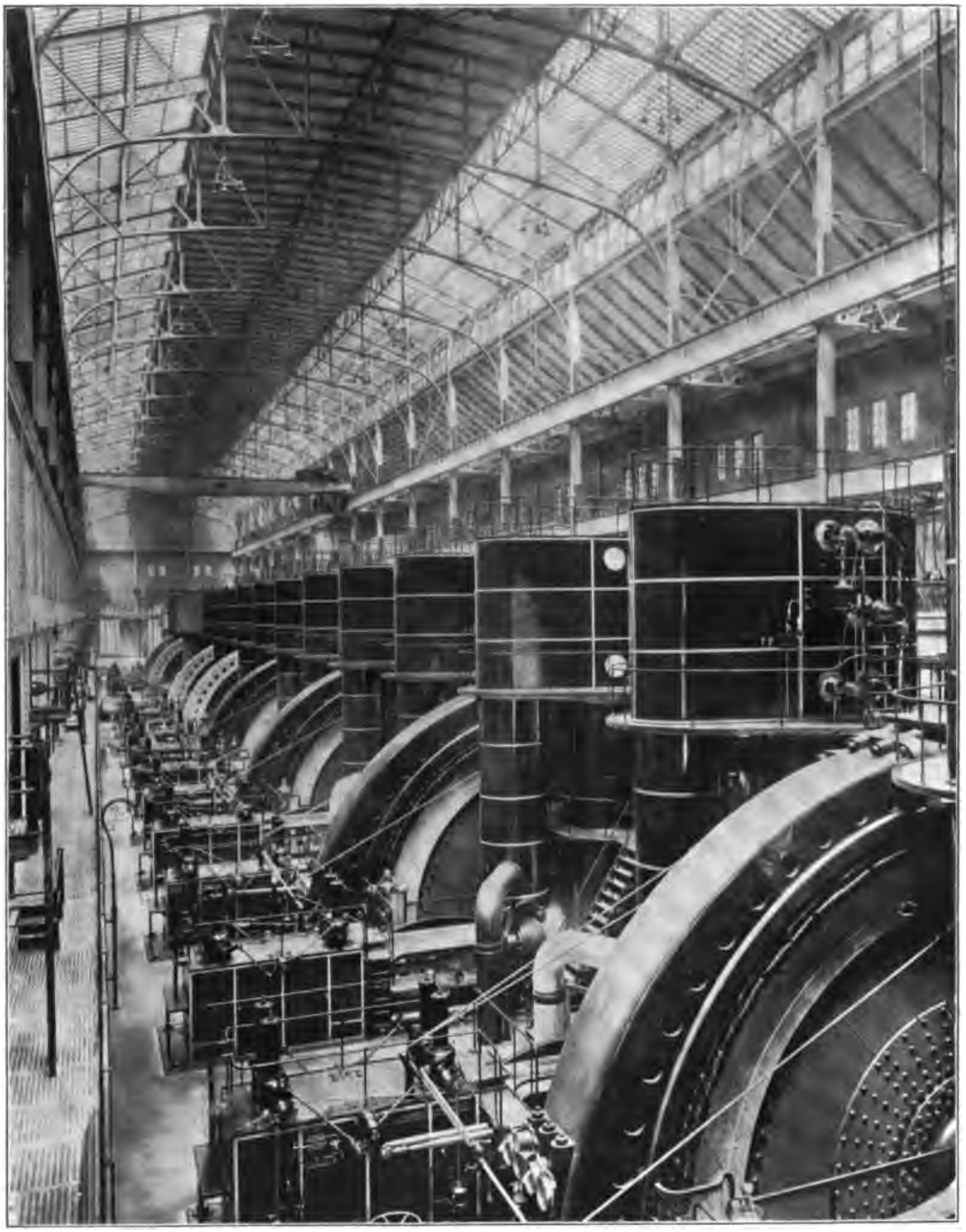


Generating Room of 59th Street Power Plant of the Interborough Rapid Transit Co. (Subway) New York.

Largest reciprocating Engine Plant in the world. Present installation consists of nine 7500 H.P. Engines and three 1250 K.W. Turbo-Generators. Ultimate maximum capacity between 130,000 and 150,000 H.P.

Frontispiece.

STEAM-ELECTRIC POWER PLANTS

A Practical Treatise on the Design of Central Light and Power Stations and their Economical Construction and Operation

BY

FRANK KOESTER

CONSULTING AND DESIGNING ENGINEER

MEMBER VEREIN DEUTSCHER INGENIEURE, ASSOCIATE MEMBER AMERICAN INSTITUTE ELECTRICAL ENGINEERS

NEW YORK

D. VAN NOSTRAND COMPANY

23 MURRAY AND 27 WARREN STS.

1908

ROBERT DRUMMOND COMPANY, PRINTERS, NEW YORK

PREFACE.

It is the aim of the Author, in this volume, to give such information in regard to modern power plant practice as is essential to the engineer in designing steam-electric power plants. No attempt has been made to treat the design of machinery, such as boilers, turbines, generators, etc., since excellent separate works on the subject already exist, and it would be impossible to combine so much in a single volume.

This book is compiled to a great extent from the experience in America and Europe, of the Author, who has been closely identified with the design of plants for Europe, Asia, Africa, Central and South America, as well as the construction and operation of plants of 100 to 24,000 K.W. normal capacity. For the purpose of studying American power plants on a broader scale, their practical method of design, construction and operation, he has been identified in America for a number of years with some of the largest and most prominent plants in the country, varying from 500 to 60,000 K.W. normal capacity.

For a number of years he has contributed to the technical press and to technical societies on both sides of the Atlantic articles on the design of power plants, and is indebted to the following Journals for permission to embody a few of these articles which have, however, been partly rewritten, considerably extended, or revised:

Electrical Review (N.Y.) for the chapter "The Design of Small Power Plants", and "The Vienna Power Plants"; *Power* for the article "Coal Handling System", and "The St. Denis Power Plant, Paris"; *Street Railway Review* for the article "High Pressure Piping", and "Superheaters"; *Zeitschrift des Vereines deutscher Ingenieure,* for the article "The 59th Street Power Plant, New York".

The Author is of the opinion that a good illustration may tell more than a long discussion, and has, therefore, added numerous cuts, many of which have accompanied his articles. For these he is indebted to various engineering companies, manufacturers, and to the following Journals, besides those already mentioned: *Street Railway Journal, Electrical World, Engineering Record, Engineering News, The Engineer, Engineering Magazine, Western Electrician, The Tramway and Railway World, Journal of the Institution of Electrical Engineers* (London), *Journal le Génie Civil, Schweizer Bauzeitung, Zeitschrift des Oesterr. Ingenieur und Architekten Vereines, Elektrische Kraftbetriebe und Bahnen, etc.*

THE AUTHOR.

NEW YORK CITY, *January,* 1908.

CONTENTS.

CHAPTER I.

PAGES

GENERAL REMARKS: Practical Problems; Efficiency; Cost of Plants 1–8

CHAPTER II.

LOCATION: Introductory; Current Distribution; Coal Supply; Water Supply; Space for Future Extension; Cost of Land; Character of Soil; Local Labor Supply 9–12

GENERAL LAYOUT: General Consideration; Complete Unit System; Boiler House; Engine House; Switching Room; Coal Storage Plant; Auxiliary Buildings 12–27

COAL STORAGE: Introductory; Exposed Coal Pile; Spontaneous Combustion; Character of Storage Plants; Description of Various Storage Plants; Comparison of Various Systems; Overhead Bunkers; Bunker Fires 27–38

CONDENSER WATER SUPPLY: Inlet and Outlet Tunnels; Screen Chamber; Shut-off Gates; Area of Tunnel and Screens; Arrangement of Inlet and Outlet Tunnels; Scarcity of Condenser Water 38–40

CHAPTER III.

EXCAVATION AND FOUNDATION: Selection of Site; Test Holes; Character of Soil; Concrete Mat Construction; Concrete Piles; Test Piles; Bearing Power of Soil; Weight of Masonry; Size of Foundations; Location of Foundations; Concrete Forms; Concrete Mixture; Grouting; Waterproofing 41–48

BUILDING: Material; Floors; Pipe Trenches; Switchboard Gallery; Walls; Windows; Doors; Ventilators; Stairways and Elevators; Toilets and Plumbing; Heating and Ventilation; Roof; Leaders 48–58

STRUCTURAL STEEL: Roof Construction; Crane Runway; Building Material; Framing; Type of Columns; Floor Loads; Fiber Stresses; Expansion Joints; Column Base; Floor Beams, etc.; Structural Steel of Recent Plants; Workmanship; Inspection; Painting; Insulation of Steel Frame; Character of Steel 58–69

ARCHITECTURAL FEATURES: Review; Windows and Doors; Crane; Walls; Floors; Pipe Trenches; Galleries; Switchboard; Boiler Room; Removal of Ashes; Coal Storage Plant; Chimneys; Conclusion 69–84

CHAPTER IV.

PAGES

BOILERS: Type of Boilers; Safety; Simplicity; Durability; Water Circulation; Heating Surface; Grate Surface; Efficiency; Setting; Trimmings; Size; Babcock & Wilcox Boilers; Stirling Boilers; Wickes Boilers; Foreign Types of Boilers; Conclusion 85–99

MECHANICAL STOKERS AND GRATES: Advantages and Disadvantages; Systems of Stokers; Grates 99–104

COAL: Introductory; Heat Value; Character of Coal; Analysis 104–113

COMBUSTION: Combustion; Air Required; CO_2 Recorder 113–119

DRAFT: Meaning; Production; Loss; Chimney Draft; Mechanical Draft; Forced Draft; Induced Draft; Steam Blower 119–130

SMOKE FLUES: Character; Shape; Size; Expansion Joints; Leakage; Doors; Dampers; Automatic Regulator 131–136

CHIMNEYS: Character; Material: Radial Brick; Reinforced Concrete; Steel Chimneys; Guyed Chimneys; Self-Supporting Chimneys; Lining; Baffle Wall; Ladders; Lightning Arresters 136–147

BOILER FEED WATER: Pure Water; Impure Water; Boiler Corrosion; Mud; Boiler Scale; Scum; Dervaux-Reisert Purifier; Storage 147–154

FEED-WATER HEATERS: Open Heater; Closed Heater; Economizer; Percentage of Gain 154–163

SUPERHEATERS: Classification; Material; Cross-Section; Circulation of Steam and Flow of Gases; Controlling Temperature; Velocity of Steam; Size; Types . . . 163–175

SUPERHEATED STEAM: Saturated Steam; Superheated Steam 175–179

CHAPTER V.

PIPING, HIGH-PRESSURE: Introductory; Size of Pipes; General Consideration; System of Piping; Expansion; Anchors; Supports and Hangers; Fittings; Flanges; Valves; Drip System; Pipe Covering; Boiler Feed Piping; Boiler Blow-Off Piping 180–217

LOW-PRESSURE PIPING: Size of Exhaust Pipes; Material; Fittings; Drips; Circulating Water Piping; Vacuum and Hot Well Piping; Covering 217–221

CHAPTER VI.

PRIME MOVERS: Comparison of Engine and Turbine; Size of Prime Movers 222–225

RECIPROCATING ENGINES: Classification; Valve Mechanism; Simple Engines; Compound Engines; Triple Expansion Engines; Quadruple Expansion Engines . . . 225–231

PAGES

TURBINES: Classification; Single Impulse Turbine; Compound Impulse Turbine; Reaction Turbine 231–240

CONDENSERS: Principle; Classification; Application; Condenser Water Required; Jet Condenser; Surface Condenser; Central Condenser; Vacuum Breaker; Cooling Towers; Cooling Ponds 240–261

PUMPING MACHINERY: Steam or Electric Drive; Steam Consumption of Auxiliaries; Circulating Pumps; Air Pumps; Hot-Well Pumps; House Pumps; Boiler Feed Pumps; Oil Pumps; Fire Pumps 262–268

OILING SYSTEM: Oil Required; Filtering Tanks; Oil Pumps; Supply Tanks; Oil Piping. 268–273

CHAPTER VII.

ELECTRICAL EQUIPMENT: Introductory; Generators; Exciters; Generator Leads; Switching Room; Wiring Diagram; Bus-Bar Chambers; Oil Switches; Switchboard; Storage Battery 274–291

CHAPTER VIII.

THE DESIGN OF SMALL POWER PLANTS: Introductory; Type and Size of Plant; Location of Plant; Foundation Work; Superstructure; Masonry Work, etc.; Sanitary and Architectural Features; Coal and Ash Handling Systems; Boilers, etc.; Boiler Feed-Water Supply; Smoke Flues and Chimney; Steam Piping; Turbines and Generators; Condenser Plant; Exciters and Air Compressor; Switchboard and Wiring System; Conclusion 292–317

CHAPTER IX.

TESTING POWER PLANTS: General Considerations; Preparation of Boiler Tests; Method of Boiler Tests; Reports of Boiler Tests; Method of Testing Prime Movers; Test of an Engine; Parsons Turbine Tests; Generator Tests 318–335

CHAPTER X.

DESCRIPTIVE DISCUSSION OF TYPICAL AMERICAN AND EUROPEAN LIGHT AND POWER PLANTS:

St. Denis Plant, Paris 336–349
Fifty-Ninth Street Plant, New York 349–361
Chelsea Plant, London 361–370
Fisk Street Plant, Chicago 371–381
Twin Municipal Plant, Vienna 381–397

CHAPTER XI.

PAGES

PRINCIPAL DIMENSIONS, DATA AND ILLUSTRATIONS OF RECENTLY CONSTRUCTED LIGHT AND POWER PLANTS:

Potomac Plant, Washington, D.C. 399
L Street Plant, Boston 400–405
Fifty-Ninth Street Plant, New York 406–407
Long Island City Plant 408–415
Chelsea Plant, London 416
Berlin Plants, Germany 417–422
St. Denis Plant, Paris 423
New York Central Plants, New York 424–432
D. & H. Co., Mechanicville, New York 433
Commerce St. Plant, Milwaukee 434–435
Boiler Heating Surface per K.W. Capacity 436
Comparison of Area and Volume per K.W. Capacity 436
Quincy (Mass.) Plant 437

APPENDIX.

Series of Tables of the Metric and English Weights and Measures 437–447
Index 449–455

LIST OF ILLUSTRATIONS.

Arrangement of Power Plants.

Plans.

	Page
Belfast, Ireland, Municipal	114
Carville, Newcastle upon Tyne	24
Chelsea, London	362, 364
Commerce Street, Milwaukee	433
Engine and Boiler Room	13, 18
59th Street, New York	352
Fisk Street, Chicago	372, 375
L Street, Boston	401
Moabit, Berlin	420
Oberspree, Berlin	418
Port Morris, New York	427
Portsmouth, Ohio	8
Quincy, Massachusetts	436
Small Plant	297
St. Denis, Paris	337
Turbine and Boiler Room	15, 16
Twin Municipal, Vienna	382, 388

Cross-Sections.

Belfast, Ireland, Municipal	118
Chelsea, London	364
Commerce Street, Milwaukee	434
Engine and Boiler Room	18
59th Street, New York	352
Fisk Street, Chicago	375
L Street, Boston	403
Long Island City	408
Port Morris, New York	425
Portsmouth, Ohio	8
Quincy, Massachusetts	436
Small Plant	302
St. Denis, Paris	338
Trebbiner Street, Berlin	422
Turbine and Boiler Room	19, 20
Twin Municipal, Vienna	386
Yonkers, New York	426

BUILDINGS.

EXTERIOR VIEWS.

PAGE
Delaware Avenue, Philadelphia 48
Dresden, Germany 74
59th Street, New York 350
Fisk Street, Chicago 49, 372
Greenwich, England 50
Grove Road, London 70
Hanover, Germany 73
L Street, Boston 56
Mechanicville, New York 54
Moabit, Berlin 419
Oberspree, Berlin 417
St. Denis, Paris 337
Seventy-Fourth Street, New York 57
Small Plant 293
Twin Municipal, Vienna 382
Waterside No. 2, New York 91

STRUCTURAL STEEL.

Delaware Avenue, Philadelphia 55
G. E. Co., Schenectady, New York 63
Waterside No. 2, New York 51
Williamsburg, Brooklyn 65
Columns, Types of 62
Roof Trusses, Types of 60

FOUNDATIONS, ETC.

Concrete and Wooden Piles 45
Mat Construction, Long Island City 44

CHIMNEYS.

Brick, Radial 137
Concrete, Reinforced 141
Dresden, Architectural Features 74
Munich, Architectural Features 83
Steel, Long Island City 144
Steel, Self-Supporting 143

COAL AND ASH HANDLING SYSTEMS.

Fifty-Ninth Street, New York 353
Long Island City 409
L Street, Boston 31
Moabit, Berlin 421
Rhode Island, Providence 29
Scheme 28

COAL AND ASH HANDLING SYSTEMS — *Continued.* PAGE

Shadyside, New York . . . 32, 33
St. Denis, Paris . . . 339
Twin Municipal, Vienna . . . 383
Williamsburg, Brooklyn . . . 34, 35
Willisden, London . . . 30

EQUIPMENT OF BOILER ROOMS.

BOILER ROOMS.

Fisk Street, Chicago . . . 373, 376
Frankfurt on the Main, Germany . . . 81
Hamburg, Germany . . . 85
L Street, Boston . . . 400, 402, 404
Long Island City . . . 410, 412
Port Morris, New York . . . 429
Reading R. R., Philadelphia . . . 98
St. Denis, Paris . . . 343
Stuart Street, Manchester . . . 102
Twin Municipal, Vienna . . . 380

BOILERS, STOKERS, FLUES.

Babcock and Wilcox Boiler . . . 91
Fifty-Ninth Street, New York . . . 98
Hornby, Horizontal Boiler . . . 89
Hornby, Upright Boiler . . . 90
Lancashire Boiler . . . 96
Lindhaus Boiler . . . 97
St. Denis, Paris . . . 339
Steel Work and Setting . . . 57
Stirling Boiler . . . 94
Twin Municipal, Vienna . . . 390
Stokers, Green . . . 101
" Jones . . . 103
" McClave, Grate . . . 103
" Roney . . . 101
" Roney, Pressure Record . . . 102
" Roney, Setting . . . 104
Smoke Flues, Expansion Joints . . . 132
" " Fisk Street, Chicago . . . 374
" " Damper Regulator . . . 134
" " Damper Regulator, Pressure Record . . . 135

FEED-WATER HEATERS, PURIFIERS, ETC.

Economizer, Green . . . 160
Economizer Plant, Union R. R. Co., Providence, R.I. . . . 160
Closed Heater, Arrangement of . . . 159
Closed Heater, Otis . . . 158
Open Heater, Arrangement of . . . 157

FEED-WATER HEATERS, PURIFIERS, ETC. — *Continued.*

PAGE

Open Heater, Cochrane 156
Open Heater, Stillwell 155
Purifier, Dervaux-Reisert 153
Purifier Plant, Syracuse, New York 153
Purifier Plant, Twin Municipal, Vienna 391

SUPERHEATERS.

Flow of Gases and Steam 166
Forms of Superheaters 165
Section of Tubes 161
Types, Babcock & Wilcox 98
" Buettner 160
" Cruse 178
" Dingler 163
" Forster 92
" Goehring 177
" Heizmann 175
" Hering 97
" Schwoerer 175
" Stirling 94
" Watkinson 174
Volume of Superheated Steam 176, 177, 178

PIPING, OIL FILTERS, ETC.

PIPES, VALVES, FITTINGS, ETC.

Anchor 190
Anchor Location 190
Anchor Cast Steel 188
Bracket with Adjustable Rollers 191
Bracket for Pipe Riser 193
Bends, Expansion 194
Exhaust Head 218
Expansion Joint 195
Fittings, Cast 196
Fittings, High Pressure 197
Fittings, Welded Steel, Loose Flanges 198
Flanges, Drilling, High Pressure 200
Flanges, German, High Pressure 202, 203, 204
Flanges, Fifty-Ninth Street, New York, High Pressure 201
Header System, Double 185
Header System, Ring 186
Header System, Single 184
Manifold, Welded Steel 199
Piping, Fifty-Ninth Street, New York 187
Piping, Yonkers, New York 431
Piping, Port Morris, New York 430

PIPES, VALVES, FITTINGS, ETC. — *Continued.* PAGE

Piping, Small Plant 304
Relief Valve 217
Separator, Cochrane 210
Separator, Stratton 209
Slip Joint 195
Support, Balanced, for Riser 193
Support, Anchors, Wall Sleeves 192
Swivelling Joint 189
Traps, Steam 211, 212
Valve, Back Pressure 217
" Blow-off 216
" Blow-off Cock 216
" Check, Boiler Feed 215
" Closing, Automatic 208
" Foot and Screen 220
" Gate, Taper Seat 205
" Globe German 206
" Non-Return 207
" Reducing, Anderson 209
Water Meter, Pipe Connection 221

OIL FILTERS AND SEPARATORS.

Austin Vacuum Separator 158
Baker Separator 250
Burt Filter 269
Filter Tank 271
Oil Piping of Curtis Turbine 272
Turner Filter 270
Utility Oil Extractor 218

EQUIPMENT OF GENERATING ROOMS.

GENERATING ROOMS.

Charlottenburg, Germany 79
Chelsea, London 366
Fifty-Ninth Street, New York . . . . . *frontispiece*
Fisk Street, Chicago 377
Harland & Wolff, Belfast 77
L Street, Boston 75
Long Island City 411
Moabit, Berlin 419
Oberspree, Berlin 417
Port Morris, New York 424
St. Denis, Paris 339, 343
Twin Municipal, Vienna 393

RECIPROCATING ENGINES.

PAGE
Right and Left Hand Engines 226
Engines and Turbines, Comparison 223
Compound Engine, 7500 H.P. 228
Fifty-Ninth Street Plant, New York 358
Quadruple Expansion Engine, Six Cylinder 231
Single Cylinder Engine 227
Triple Expansion Engine, Four Cylinder 230

TURBINES, ETC.

Comparison of Turbine and Reciprocating Engine 233
Brown, Boveri-Parsons Turbine 233
Curtis Turbine 239
De Laval Turbine 232
Rateau Turbine 236
Westinghouse-Parsons Turbine 237
Turbine Test Curve 329, 330, 332
Essen, Germany, 6500-K.W. Parsons 239
Fisk Street, Chicago, 9000-K.W. Curtis 378
L Street, Boston, Turbine Unit with Auxiliaries 400–405
Neasden, London 238
St. Denis, Paris, 5000-K.W. Turbo-Generator 344
St. Denis, Paris, Turbine Unit with Auxiliaries 346

CONDENSERS, PUMPS, COOLING PLANTS, ETC.

Alberger, Jet Condenser 245
Alberger, Fifty-Ninth Street, New York 246, 247
Bulkly, Jet Condenser 243
Cooling Plant 258, 260
Cooling Pond 259
Cooling Towers, German 254, 255
Cooling Towers, Alberger 256
Cooling Towers, Worthington 257
Eductor Condenser, Schutte & Koerting 261
Delaware Avenue, Philadelphia 248
Long Island City 414
Small Plant 312
St. Denis, Paris. 346
Vacuum Augmenter 249
Pumps, Air 267
" Air, St. Denis, Paris 347
" Arrangement, Fifty-Ninth Street, New York 356
" Centrifugal 267
" Motor Driven 262
" Motor Driven, Vienna 385
" Water Supply, Vienna 386

CONDENSERS, PUMPS, COOLING PLANTS, ETC. — *Continued.* PAGE

Seventy-Fourth Street, New York 241
Surface Condenser 251
Surface Condenser, Pinkston, Glasgow 241
Surface Condenser, Worthington 253
Water Supply System, Vienna 385
Vacuum Augmenter, Parsons 249
Weiss Dry Jet Condenser 242
Worthington Jet Condenser 240

EQUIPMENT OF SWITCHING ROOMS.

SWITCHING ROOMS.

Carville, Newcastle upon Tyne 281, 282
Fifty-Ninth Street, New York 280, 285
Fisk Street, Chicago 379, 380
Long Island City 275, 411, 413
Swiss Practice 286, 287
Waterside No. 2, New York 279

SWITCHBOARDS, ETC.

Charlottenburg, Germany 79
Fifty-Ninth Street, New York 360
German, Type of 289
Hamburg, Germany 288
Long Island City 413
Long Island City, Feeder Cables 276
Port Morris, New York 432
St. Denis, Paris 348
Swiss Practice 286
Swiss Practice, 6000 Volts Apparatus 287
Swiss Practice, 27,000 Volts Apparatus 287
Twin Municipal, Vienna 394, 395

WIRING DIAGRAMS.

Carville, Newcastle upon Tyne 284
Chelsea, London 369
Fifty-Ninth Street, New York 283, 359
Fisk Street, Chicago 379
Long Island City 277, 415
Port Morris, New York 429
Small Plant 315
Twin Municipal, Vienna 396

LIST OF TABLES.

	Page
Heat Losses in a Power Plant per Pound of Coal	2
Equivalent of Heat and Mechanical Units	4
Cost of Turbine Plant	6
Cost of Engine Plant	6
Cost per Unit generated of British Plants	7
Safe Bearing Power of Soil	46
Weight of Masonry	46
Floor Load of 59th St. Plant, New York	63
Structural Steel of Recent Plants	65
Boiler Horse-Power per K.W. Capacity	93
Heat Power of Coal	106
Character of Coal	110
Analyses and Heating Values of American Coals	114
Pressure in Inches Equivalent to Ounces	120
Height of Water Column due to Unbalanced Pressures in Chimneys 100 Feet High	121
Kent's Tables of Size of Chimneys	123
Christy's Table of Size of Chimneys	124
Chimney Data of Recent Power Plants	124
B.T.U. carried off by Escaping Gases	125
Weight of Air, etc.	129
Velocity of Air created by Draft	130
Percentage of Saving for each Degree of Increase in Temperature of Feed-Water Heated	161
Percentage of Saving effected by Heating Feed-Water from Initial to Final Temperature	162
Coal Needed for Superheating Steam	173
Properties of Saturated and Superheated Steam	179
Area of Circles	186
Equation of Pipes	180
Fall in Pressure in Standard 90° Bends Equivalent to Straight Pipes	181
Dimensions of Expansion Bends	192
High-Pressure Fittings	194
Tensile Strength of Pipe Material	197
Drilling of Standard High-Pressure Flanges, adopted in America	200
Standard High-Pressure Flanges, adopted in Germany	202
High-Pressure Flanges, adopted for the 59th St. Plant, New York	201
Dimensions for High-Pressure Gate Valve	205
Dimensions for High-Pressure Non-return Valves	207
Loss of Heat from Bare Steam Pipes	212
Efficiency of Pipe Covering	215
Capacity in Gallons per Minute discharged in Pipes	219

PAGE

Floor Space occupied by Prime Movers 224
Test of 5000-K.W. Curtis Turbine 234, 235
Steam Consumption of Auxiliaries 263
Steam Consumption of Pump of a 5000-K.W. Turbine 264
Test of Condenser Apparatus 265
Result of a 350-H.P. Boiler Test 319
Result of a 700-H.P. Boiler Test 321
Result of a 480-H.P. Engine Test 326
Results of Tests of Parsons Turbines of Various Sizes 327
Results of a 400-K.W. Parsons Turbine Test. 328, 329, 331
Generator Tests 333, 334, 335
Guaranteed Steam Consumption of 5500-K.W. Parsons Turbine, Chelsea Plant, London . 367
Test of Twin Municipal Plant, Vienna 397
Dimensions and Data, Potomac Plant, Washington, D.C. 399
Dimensions and Data, 59th St. Plant, New York 406
Dimensions and Data, Chelsea Plant, London 416
Dimensions and Data, St. Denis Plant, Paris. 423
Dimensions and Data, D. & H. Co. Plant, Mechanicville, New York 433
Boiler Heating Surface per K.W. Capacity 436
Area of Power House per K.W. Capacity 436
Volume of Power House per K.W. Capacity 436

APPENDIX.

Metric System of Weights and Measures. 437
Gallons Equivalent to Liters 438
Pounds per Cubic and Square Equivalent to Kilograms per Cubic and Square . . . 438
Cubic Meters and Centimeters Equivalent to Cubic Feet and Cubic Inches. 438
Kilograms per Meter and Square Meter Equivalent to Pounds per Foot and Square Foot . 439
Foot-Horse Power Equivalent to Metric Horse-Power 439
Foot-Pound Equivalent to Kilogram Meters 439
Gross Tons per Square Foot Equivalent to Metric Tons per Square Meter 439
Specific Gravities and Weights of Various Substances 440
Inches and Feet Equivalent to Millimeters and Meters 441
Square Inches and Square Feet Equivalent to Square Centimeters and Square Meters 441
Pounds and Net Tons Equivalent to Kilograms and Metric Tons 441
Units of Weights and Measures (Volume) 442
Units of Weights and Measures (Length and Surface) 443
Units of Weights and Measures (Weight) 444
Units of Weights and Measures (Miscellaneous) 445, 446
Decimals of a Foot, Equivalent to Inches and Fractions of an Inch 447
Decimal Inches and Millimeters Equivalent to Fractions of an Inch 447

STEAM-ELECTRIC POWER PLANTS.

CHAPTER I.

GENERAL REMARKS, EFFICIENCY AND COST OF PLANTS.

Practical Problems. — The problems involved in the design of steam-electric power plants must necessarily be treated in conjunction with cost of construction, installation, operation and maintenance, it being the ultimate aim of engineer and capitalist to produce electricity at a minimum of expense. To accomplish this end, much experience is necessary. It is not the province of the engineer as a designer of power plants, to design any particular machine or device, but to provide, by selection from different makes, an assemblage of machines and devices, each designed to perform its particular function in the most economical manner, and to combine them so as to create one complete unit for the purpose of generating electricity from coal on a commercially satisfactory basis. Upon his skill in selecting machines and devices will depend the satisfactory and economical operation of the plant. He must exercise great care and foresight in arranging these devices since, for example, a prime mover, purchased to operate at a certain rate of steam consumption per indicated horse power, and not properly connected to the boilers and auxiliary devices, may have its steam consumption materially increased.

In laying out a plant, selecting the various machines and appliances, arranging and connecting them in their proper relation, originality should be exercised. No designer should unreservedly copy the scheme of an existing plant, since what would be economical in one plant might be the reverse in another.

Any attempt to standardize the design of power plants would operate to the disadvantage of designers, inasmuch as it would entirely eliminate small competitors and would throw all the business to a few large concerns, who would in time become too independent, and would stay progress, since these manufacturers would have no incentive to improve their machines, and improvements would be checked if the designer had to accept their goods as offered.

The various branches of the work, excavation, foundations and structural; architectural, mechanical and electrical, are so closely allied that it is absolutely necessary that the entire design of a plant should be placed under one engineer who should be in charge of the designers of the various branches. If this or similar method be not followed, confusion will result, delaying the work and incurring additional expense; complete co-operation will not exist and the various designers will conflict with one another; for instance, the same article or work may appear in two or more drawings or specifications, or may be entirely omitted, one designer considering it as part of another's work.

Before submitting plans and specifications to the contractors for bids, they should be complete in every detail, in fact, they should be working drawings. If this plan be followed the extras will be minimized. Extras are usually overcharged, since it is by this means that some contractors look for their profits. For instance, the contract for the structural steel may be let from a preliminary plan, on a per pound basis of say from three to four cents; when, however, the plans are worked out in detail, it may be found that there are a number of staircases, openings, gratings, ladders and railings required but not shown on the preliminary plans; the contractor, on the plea that more workmanship is required with this kind of work, may raise his price to seven or eight cents per pound, or even more. A considerable sum of money will be saved by embodying all this work in one contract. For certain features, such as chimneys, boilers, and the main prime movers, etc., preliminary bids may be asked for from rough plans to ascertain the approximate cost of the plant. This may be necessary, when the designer is limited to a certain fixed sum, and especially if the experience of the designer is limited.

The specifications should be drawn so as to amplify and explain the plans, and each contractor's specification should be so drawn that there will be no confusion, one contractor starting where the previous contractor stops, so that the work will not overlap, or gaps be left.

Efficiency.—The efficiency of a steam-electric plant is low, ranging from 8 per cent to 16 per cent of the heat value of the coal. Sixteen per cent is extremely economical

TABLE I.—APPROXIMATE LOSSES IN A WELL-CONDUCTED FIRST-CLASS BOWER PLANT, PER POUND OF COAL.

Subject.	Losses in B. T. U. and Percentages per Pound of Coal.	
	14,000 B. T. U.	100 %.
Ashes	210	1.5
Radiation and leakage of boiler	560	4.
Radiation and leakage of flue	140	1.0
Gases through chimney	1,960	14.
Blow-off and leakage	210	1.5
Radiation and leakage of piping	210	1.5
Friction and leakage of engine	140	1.0
Rejected to condensers	8,540	61.
Electrical loss	28	0.2
Required for all auxiliaries	910	6.5
	12,908	92.2

Returned by Feed Water Heater 5 per cent or 700 B.T.U.
Delivered to the bus-bars 105 − 92.2 = 12.8 per cent or 1.792 B.T.U.

and can only be secured by the best designed and equipped plant and by scientific operation. The average plant of recent construction operates with an efficiency of from 10 per cent to 14 per cent.

The accompanying table, Fig. 1, shows the approximate loss per pound of coal in a well conducted, first-class power plant. It will be noticed that the coal is assumed to have a heating value of 14,000 B.T.U. of which the equivalent of 12.8 per cent or 1792 B.T.U. are delivered to the bus-bars.

Since the efficiency of a steam-electric plant is so low, every increase in percentage of economy, be it ever so small a fraction, will materially improve the general results. The loss of heat accompanying the escaping flue gases may be minimized by employing a properly designed boiler, properly set and connected to a well designed chimney. The use of mechanical draught may still further reduce this loss, while at the same time an intelligent and well conducted fire-room force is also conducive to economy; for instance, the installation of carbon dioxide ($C\,O_2$) recorders, from which the fireman can read whether he is having complete combustion of the fuel or not, will facilitate intelligent operation.

Another point which the designer should consider is the method of heating the feed water. This may be done either by the exhaust steam of the auxiliary machinery, with economizers, or a combination of both. The higher the temperature of the feed water the greater the gain.

An important factor in the economy of power plants is the superheater. By its installation the steam consumption is lowered, because the condensation in the mains and engine cylinders is considerably reduced. Practice has proved that with the use of modern engines this reduction amounts to 1 per cent of the steam consumption for each 5 degrees C. (9 degrees Fahr.) of superheat. This applies, of course, up to a certain degree of temperature, above which there is no further increase in economy. The prime movers selected should be capable of withstanding a high degree of temperature without material depreciation. By high degree of temperature in American practice is meant a maximum temperature of 500 to 600 degrees Fahr., or in Continental practice, 600 to 700 degrees Fahr., and even higher.

In selecting the prime mover, either reciprocating engine or steam turbine, one with the lowest steam consumption, provided the first cost is not too excessive, should be used. The guarantee test should be made on the power plant under actual working conditions and under no circumstances should it be made in the manufacturer's shops, since the conditions may be entirely different, the manufacturer's testing plant being perhaps fitted for ideal conditions.

A "modern" prime mover should be able to operate with a steam consumption under normal rated load of from 11 to 10 pounds per I.H.P. hour, or lower. Manufacturers on the continent of Europe sell prime movers (reciprocating engines and turbines) with a guaranteed steam consumption of from 10 to 9 pounds and lower. These figures are, of course, based on the use of high temperature steam and a vacuum of approximately 27 inches.

In the selection of auxiliary machinery, such as condensers and pumps, the type of prime movers should be considered. With the use of turbines, surface condensers are usually of greater efficiency; while with reciprocating engines, jet condensers may be successfully employed. It is a recognized fact that the greater the number of expansions in a turbine, the higher will be the efficiency, which cannot strictly be said to apply to the reciprocating engine, because of the heavy cylinder condensation, due to the alternate heating and cooling of the walls of the cylinders; while with many makes of turbines a uniform temperature is maintained throughout, and with each inch increase in vacuum over 26 inches, a saving of from 3 per cent to 5 per cent is

obtained. Of course, larger apparatus is required to obtain high vacuum, and it is, therefore, especially essential to select pumps of high efficiency.

There are, of course, many other items to be taken into consideration to secure harmonious operation of the various machines, the ultimate aim being to turn out a kilowatt for the least amount of money. The economical operation of a plant is due to a great extent, first to the designer, who selects high efficiency machinery and combines the same properly, and secondly to the operators.

The operation of a steam-electric power plant may be divided into two main stages: the first, the utilization of the latent heat in the coal by the conversion of water into steam ; the second, the conversion of the energy of the steam into electrical energy.

The heat latent in the coal is expressed, in English speaking countries, in British Thermal units (B.T.U.). One B.T.U. is the amount of heat required to raise one pound of water (at 39.1 degrees Fahr.) one degree Fahr. In countries where the metric system is used the unit of heat is called the Calorie (C.), and is the amount of heat required to raise one kilogram, which equals one liter of water (at 4 degrees C.), one degree C. There is also the small calorie (c) or gram calorie, which is the one-thousandth part of a calorie and is used exclusively for scientific work.

In order to convert B.T.U. to C., divide the number of B.T.U. by 3.968, or multiply by 0.252. For the purpose of transforming heat units into mechanical units the following Table II gives the equivalents:

TABLE II.—EQUIVALENTS OF HEAT AND MECHANICAL UNITS IN ENGLISH AND METRIC SYSTEMS.

	B. T. U.	Foot Pound	Calorie.	Meter Kilogram.
British Thermal Units	1	778	0.2521	107.6
Foot Pounds	0.001285	1	0.000324	0.1382
Calorie	3.968	3081	1	427
Meter Kilogram	0.0093	7.23	0.00234	1

The size of the plant is usually expressed in horse power (H.P.) or kilowatt (K.W.), the latter being more generally used since the introduction of the steam turbine. One H.P. equals 33,000 foot pounds, or 75 meter kilograms, or .746 K.W.; the H.P. of the prime movers should be 50 per cent in excess of the output of the generator in K.W. — for instance, a 1,000 K.W. generator will require a 1,500 H.P. prime mover. This percentage of increase includes the friction losses since, actually, one K.W. equals 1.34 H.P. If the output of a combined unit is given in H.P., deduct 33⅓ per cent to convert to K.W.

Cost.— The cost of a power plant depends upon its character and equipment, and, to a very great extent, upon the capability of the designer. The greatest "errors" made by designers are in the choice of machinery for particular conditions. This is due to lack of experience and unfamiliarity with up-to-date machinery. Many such "errors" are discovered after the machinery has been bought, and during the process of designing, while many other errors are discovered during the course of construction, and especially afterwards in the operation. In fact, some plants have been designed with too small a boiler capacity on account of which blowers have to be added, but, owing

to the design, it is impossible properly to locate these blowers. Other cases have occurred with the structural steel in the basement X braced, thus preventing the laying of air ducts. To overcome this difficulty, the more expensive induced draught system is installed, or, if possible, the height of the chimney is increased. On the other hand, plants have been installed with the boiler capacity some 30 to 40 per cent too large. This, of course, would not affect the operation, but, besides the increased first cost, it entails a decided increase of the interest on the investment, and additional depreciation and maintenance. Other plants have been designed with the entire piping system more than 50 per cent too large. In addition to the piping being designed too large, some of the pipes are entirely unnecessary. Another plant has been designed, so that practically the entire condenser equipment of eight 5000 K.W. units had to be replaced by another system.

The enormous expense of these changes may be easily appreciated. It will, therefore, be seen that it is a paying investment to engage, or consult, men of broad experience.

The ratio of operating and maintenance costs of reciprocating engine and steam turbine plants may be 10 to 8 or 8½. This is due to lower steam and coal consumption in the latter case, since the water of condensation may be returned directly to the boiler. The labor for attendance on a turbine plant is practically negligible. In further considering the cost of a power plant, the advisability of installing a condenser must be carefully considered. This, however, does not necessarily mean that the omitting of the condenser apparatus will result in a lower first cost, since, on account of the higher steam consumption of a non-condensing engine, which may reach 30 to 40 per cent and even higher, larger prime movers, boilers, and consequently auxiliary machinery and building must be provided.

The accompanying Tables, III and IV, give average prices of plants equipped with turbines and reciprocating engines. It is assumed that units are installed of 3,000 to 5,000 K.W. capacity or above. It will also be noticed that each table consists of two columns, the first giving prices arrived at by skilled engineering and favorable conditions, the second giving prices of plants which were high, due to inferior design and selection of equipment. These latter figures do not, however, represent the highest cost of plants actually installed, for it is understood that the L Street Station in Boston cost about $125.00 per K.W., while the cost of the 59th Street Station, New York City, amounts to nearly $150.00 per K.W. This large variation in cost is only partly due to high costs of buildings, which are recognized as the finest buildings in the country for the purpose. The superstructure of the latter station amounts to $32.00 per K.W., while the condenser equipment of this station and the boiler equipment of the former power station are excessively high.

Reverting to these tables it will be noted, by comparison, that the turbine plants are somewhat lower in cost than the engine plants. This is owing to the smaller foundations required, and, possibly, also to the fact that a smaller building serves. Furthermore, the turbo-generator costs less than combined engines and generator, although the prices of the former are generally governed by the prices of the latter.

Again, the condenser equipment is more expensive for the turbine plants, for the

surface condensers usually installed cost more, and, owing to the higher vacuum maintained, larger pumps are required.

These costs apply to plants of medium and large capacity, the costs of small size plants being treated in Chapter VIII. It must be borne in mind that the cost per K.W. increases very rapidly as the capacity of plant is decreased.

TABLE III. — COST OF TURBINE PLANTS.

Excavations and Foundations	$2.00	$2.50
Building	10.00	15.00
Tunnels	1.75	4.00
Flues and Stacks	2.50	3.50
Boilers and Stokers	8.50	12.00
Superheaters	2.00	2.50
Economizers	2.00	2.25
Coal and Ash Handling System	1.50	3.00
Blowers and Ducts	1.00	1.50
Pumps and Tanks	1.00	1.25
Piping, Complete	2.25	4.50
Turbo-Generators	22.00	25.00
Condensers, Surface	5.00	8.00
Exciters	.75	1.00
Cranes	.25	.50
Switchboard	2.00	3.50
Labor, etc.	1.00	2.00
	$65.50	$92.00

TABLE IV. — COST OF ENGINE PLANTS.

Excavation and Foundation	$3.00	$5.00
Building	10.00	20.00
Tunnels	1.50	2.75
Flues and Stacks	2.50	3.50
Boilers and Stokers	8.50	12.00
Superheaters	1.75	2.25
Economizers	2.00	2.25
Coal and Ash Handling System	1.50	3.00
Blowers and Ducts	1.00	1.50
Pumps and Tanks	1.00	1.25
Piping, Complete	2.50	5.00
Engines	18.00	22.00
Condensers, Jet	3.00	5.00
Exciters	.75	1.00
Generators	10.00	12.00
Cranes	.25	.50
Switchboard	2.00	3.50
Labor, etc.	1.00	2.00
	$70.25	$104.50

During the discussion of a paper on power station design, by Messrs. Merz and McClellan before the Institute of Electrical Engineers, London, Mr. H. L. Leach presented the accompanying table, showing the relative cost per unit generated in London and in provincial plants. It is hardly necessary to make any further comment on it, since it speaks for itself.

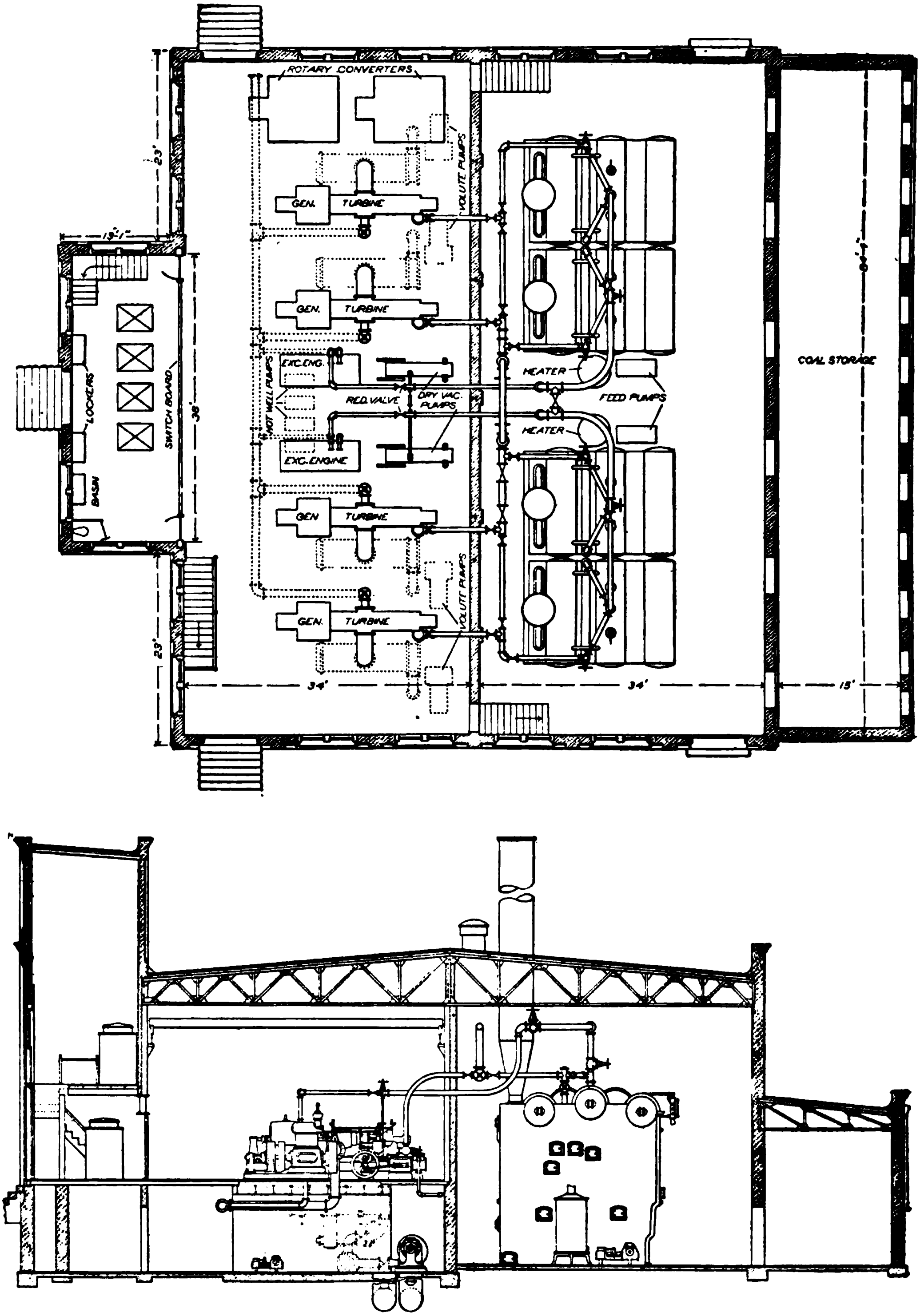
TABLE V. — SHOWING RELATIVE COST PER UNIT GENERATED IN LONDON AND PROVINCIAL PLANTS.

Year of Working.	Station.	Units Generated.	Per Unit Generated.				Works Costs.			Load Factor.	Cost per Kilowatt.
			Coal.	Oil, Water, and Stores.	Wages.	Repairs.	Engine-room Costs.	Interest and Depreciation at 10 per cent.	Total Costs.		
	Merz & McClellan		d. .150	d. .020	d. .044	d. .036	d. .250	d. .275	d. .525	Per Cent. 30.00	£ 30
1902	Newcastle-on-Tyne Co. . . .	† 7,345,786	.150	.023	.082	.105	.360	1.187	1.547	13.98	51
1902	Bradford Corporation	10,125,189	.234	.045	.072	.117	.468	.498	.966	20.93	33
1902–3	Brighton "	† 8,122,966	.603	.060	.187	.170	1.020	.704	1.724	17.38	43
1902–3	Edinburgh "	10,196,954	.246	.035	.070	.194	.545	.908	1.453	14.31	37
1902–3	Glasgow "	13,197,612	.226	.043	.122	.252	.643	.748	1.391	14.01	33
1902–3	Leeds "	† 5,931,533	.210	.023	.127	.105	.465	1.533	1.998	12.31	43
1902	Liverpool "	†25,762,314	.333	.054	.135	.117	.639	.623	1.262	25.11	32
1903	City of London Co.	†17,419,352	.374	.026	.161	.297	.858	—	—	12.26	—
1902	City of London Co.	†17,676,786	.472	.040	.176	.304	.992	1.633	2.625	12.07	66
1902	St. James & Pall Mall Co. .	7,338,971	.601	.064	.176	.185	1.026	1.079	2.105	17.69	61
1902	City & South London Ry. .	* 3,781,087	.310	.046	.056	.028	.440	—	—	49.20	—

NOTE. — The figures for interest and depreciation and cost per kilowatt refer only to cost of land, buildings, machinery and plant.

* For half-year ended June 30, 1902. See *Proceedings of the Institution of Electrical Engineers*, Vol. 33, "The City and South London Railway: Working Results of the Three-Wire System Applied to Traction, etc.," by P. V. McMahon.

† Calculated from units sold at following efficiencies of distribution: — Newcastle, 75 per cent; Brighton, 85 per cent; Leeds, 75 per cent; Liverpool, 90 per cent; City of London, 1903, 85 per cent; 1902, 80 per cent.



Portsmouth (Ohio) Light and Power Plant (*The Engineer*).

CHAPTER II.

LOCATION.

Introductory. — Modern systems of electrical distribution permit of much greater liberty in the selection of a site for the main generating station than was possible in the early days of the art. Formerly it was almost a necessity that the station should be situated at the central portion of the area served, and in such locations land was high priced and difficult to secure. As a result many central stations were built on abnormal designs, in the endeavor to crowd sufficient generating capacity into the limited area available. In such plants it was impossible to secure the best results, and the ultimate fate of many has been to become sub-stations, at which high-tension current is transformed to a voltage suited for the local service. By the use of high-tension systems of distribution, the radius within which it is possible to locate the main generating station has been enormously extended, and improved facilities thereby obtainable for the handling of coal and ashes, etc. This reduces the operating expenses and fixed charges, to an extent that more than counterbalances the transmission and transformer losses.

In short, the most important points which have to be considered in the location of the main generating station, are as follows, viz.:

I. System of distribution to be used.

II. Facility with which coal may be received and ashes disposed of.

III. Water supply available for boiler feed and condensers.

IV. Space available for future expansion and coal storage.

V. The cost of the land.

VI. The character of the ground with reference to its influence upon the expense required in putting in suitable foundations.

VII. Convenience and accessibility of the site for the operating force, the available supply of labor, etc.

Current Distribution. — The system of distribution adopted will determine whether the site must be in the more expensive business district, as in the case with low-tension lines, or in a neighborhood where land is less costly; in the manufacturing suburbs or at a considerable distance, as is permissible when high-tension transmission lines are to be used, though in this latter case it may not always be possible to use high-tension distributing systems on account of local laws and regulations.

Coal Supply. — It is impossible to secure permission to erect a power plant in certain sections of some cities, owing to the smoke nuisance, while in other cities permission may

be granted, provided the buildings conform in appearance, and will be maintained at all times in harmony with the surroundings; that suitable means will be provided for the prevention of smoke and for the disposal of waste steam, etc., and that the hours during which fuel may be delivered and ashes removed will be restricted to such as will cause the least inconvenience to the neighborhood. Plants in such localities are hampered in many ways and are liable to numerous suits for damages, with their resulting expense. As an example of this a decision was handed down in the appellate division of the Supreme Court of the State of New York, whereby the 26th Street Station of the Edison Electric Illuminating Company of New York City, which was built in 1888, was declared a nuisance, and damages were awarded to an adjacent property holder.

In almost all cases a good location for a generating station is near a gas works, or in a factory neighborhood, such plants being usually located close to a railroad or waterway, by means of which coal and ashes can be conveniently handled. Such conveniences are of great service during construction for the delivery of building materials, machinery, etc. In such localities it is usually possible to arrange for a side track to be built to the property, whence tracks can be laid into the building so that boilers and heavy machinery can be readily handled. When it is possible to do so, a site should be selected where both land and water transportation facilities are present, to insure continuity of fuel supply. To guard against interruptions, provision should be made, near the plant if possible, for the storage of a sufficient quantity of coal to carry over the probable length of time of such interruptions, during several weeks or for longer periods if it be possible.

The New York Edison Company experienced considerable trouble in 1902 when there was a strike in the anthracite coal regions, of several months duration, and they have since erected a large coal storage plant as a reserve supply for their various generating stations located in New York City. Owing to the fact that it was impossible to secure sufficient space for this purpose, at a reasonable cost, at the various stations, this plant has been located at Shadyside, N.J., on the Hudson River, where the coal is usually delivered in cars, and whence it is transported in barges either directly to the generating station or to a pier whence it is carted to the power plant. The complete plant provides a storage capacity of 150,000 tons, two-thirds for anthracite coal, and the remainder for bituminous coal.

In the case of the twin municipal plant of Vienna, Austria, each portion has been provided with coal storage for six weeks, while in many other European plants the coal capacity is such as will carry them over the frequent short strikes, lasting from two to eight weeks.

It might be considered a good plan to locate the generating station adjacent to the coal mine, whereby the cost of fuel would be greatly reduced, and to distribute the current to cities and factories by high-tension transmission lines. This project, however, is by no means a new one, and has been discussed several times in the technical press. It is perfectly feasible and may yet be done. Some of the more prominent firms in Germany recently proposed to erect a large central station, in the Rhenish-Westphalian

coal region, which is one of the largest manufacturing districts of the Empire. The plan has been partly carried out with success.

In the case of the Mexican Light and Power Company, supplying the City of Mexico, we have an example of the transmission of electricity over a distance of 173 miles (the initial voltage being 67,500). There are instances in which a tension of 80,000 volts is used, while lines operated with 100,000 and more are now under consideration. These plants, however, are operated by water power and the sites of the stations were determined by this factor. With steam-operated plants the question is simply whether it is cheaper to transport the coal to a station close to the center of distribution, or to transmit current over this distance, but at the same time the liability to interruptions must be taken into account. Unreliable service will result in serious competition springing up, with consequent loss of business.

Water Supply. — The available water supply is an important question, particularly for condensation, and for this reason many plants using reciprocating engines were located at the water's edge. In such plants the vacuum is rarely higher than 25 to 26 inches, while with the advent of the steam turbine much higher vacua became desirable owing to the increased economy of the turbine under such conditions, and thereby the quantity of circulating water required has been doubled and in some cases nearly trebled as compared with the requirements of a reciprocating plant.

From the foregoing it will be seen that the water question is vital. Where the plant is located adjacent to tide water this question is complicated by the fact that it is undesirable to use salt water for boiler feed purposes; therefore, it is necessary either to draw water from the available local water supply, or, in some cases, the water must be piped a considerable distance, and the amount of water required will depend upon whether surface or jet condensers are used; in the one case only sufficient water will be required to supply the various losses, while in the other the entire amount required for the boilers must be supplied.

Space for Future Extension. — It is desirable that the site selected should have room enough to permit of the natural growth of the plant, and be of sufficient additional area to permit of adequate coal storage, suited to present and future requirements. In many cases such considerations have been neglected. In some cases local considerations are such that it is almost impossible to obtain a site with these features; in other cases the financial condition of the company, in its early days, has prevented the acquirement of more land than absolutely necessary for immediate purposes. Strong companies, too, have suffered from mismanagement at the start; in some cases from short sightedness on the part of the directorate, in others, from a desire to secure personal profit from the company on the part of some official.

Cost of Land. — In many cases the cost of the land has been the deciding factor in regard to the location of the plant, and all other considerations have been ignored, notwithstanding the fact that such locations may add considerably to the operating expenses,

for the reason that coal may have to be hauled by wagons at considerable expense and ashes disposed of in a similar manner, and as the expense of this handling is a continual tax, a more conveniently located site will, in such cases, be found necessary in a short time. Cases have arisen in which it was found cheaper to abandon the original station, as soon as it was feasible to construct a new one, to care for the increased load, at a point where operating expenses were lower.

Character of Soil.—The character of the soil may be an important factor in the selection of a site for a power house, the most desirable being, of course, that which entails the least expense for foundations. At the same time it must be considered, that the expense of the foundations has not only to be met at the start but thereafter becomes a factor in the fixed charges. It is possible, however, that a site (although requiring expensive pile foundations) may be preferable to one whose foundations call for a smaller initial outlay, when other things are considered. It is desirable to select and secure options on several sites, and if this procedure be followed, these options should permit borings to be made from which it will be possible to determine the depth and size of the heaviest foundations required. A small expense incurred in this manner will often enable large sums to be saved. The subject of foundations will be further considered under that heading.

Local Labor Supply.—The convenience and accessibility of the site for the operating force and the labor supply, or the attractions which the neighborhood present that would be liable to make the operating force contented in the locality, should be considered. It is comparatively easy to import a force of men when such cannot be secured in the vicinity, but it takes more than a steady position to hold men, except in times of business depression when the labor market is over supplied, and should the plant be inconveniently located with regard to residential districts, suitable for the various grades of employees, it will usually be found that a certain amount of difficulty will be met with in holding some of the most desirable men. On the contrary, in plants more favorably located, it will be found that positions are sought after, and, in a manner, such a location becomes an invisible asset of no mean value.

GENERAL LAYOUT OF POWER PLANTS.

General Consideration.—This heading may be treated in the following subdivisions:

I. Boiler House.
II. Engine House.
III. Switch Room.
IV. Coal Storage Plant.
V. Auxiliary Buildings.

The practice of making the boiler and engine houses separate buildings has long since been abandoned, and it is not to-day considered good practice to use the long steam pipes which are required to span the space between the buildings. These

long pipes caused a great deal of condensation, resulting in wet steam for the engines, and were dangerous, owing to the likelihood of water collecting and being carried over to the engine in such large quantities that the relief valves on the cylinders could not care for it. Short pipes are also much cheaper to install and to keep in repair. It has been the practice for the last eight or ten years to locate the boiler house at the side of the engine house, as is shown in Fig. 2. A light division wall may separate the two

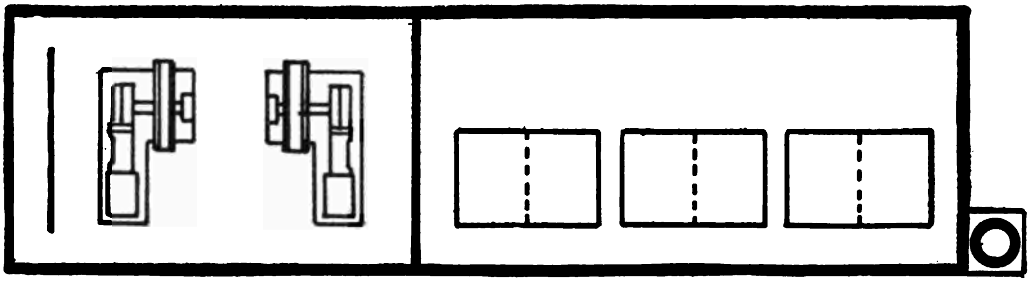


FIG. 1.

rooms, and they may or may not be covered by a roof common to both, depending upon the size and upon insurance regulations. Where conditions are such that this arrangement is not possible, owing to the shape of the plot of ground, an arrangement which may be utilized is shown in Fig. 1. As can be seen, with this arrangement the

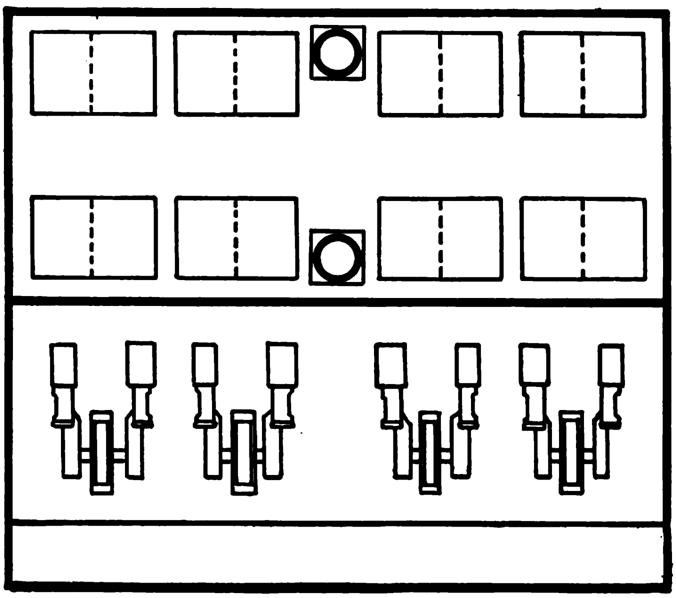


FIG. 2.

steam pipes may be of enormous length, and therefore it is not considered good practice, and very few plants have been built along these lines. Where these conditions are encountered it would be preferable, especially in cities where land is expensive, to put

the boiler room above the engine room, as, for example, in the power plant at Bristol, England, and the Berlin Underground and Elevated Railroad plant, and the Duane Street station of the New York Edison Company. It may seem proper that the boilers should be on the first floor, with the engines above them, but in actual practice it has proved inadvisable, for it is desirable that reciprocating engines be placed on the ground floor on a good solid foundation. However, it is possible with the steam turbine to follow the former arrangement, for there is no appreciable vibration, and the weight is far less than that of reciprocating engine.

In Fig. 2 it will be noticed the two rows of boilers are divided by a common firing aisle, a system adopted by the Chelsea plant of London, Interborough Rapid Transit plants of New York and the twin municipal plant of Vienna; — all plants of recent construction. Occasionally one will find the boiler house provided with two rows of boilers similar to Fig. 2, but with the boilers placed back to back, thus necessitating two firing aisles. A system similar to this is characteristic of French plants, with the exception that the generating room is between the two rows of boilers, as indicated by dotted lines in Fig. 3; for example, the Metropolitan Company's power house in Paris,

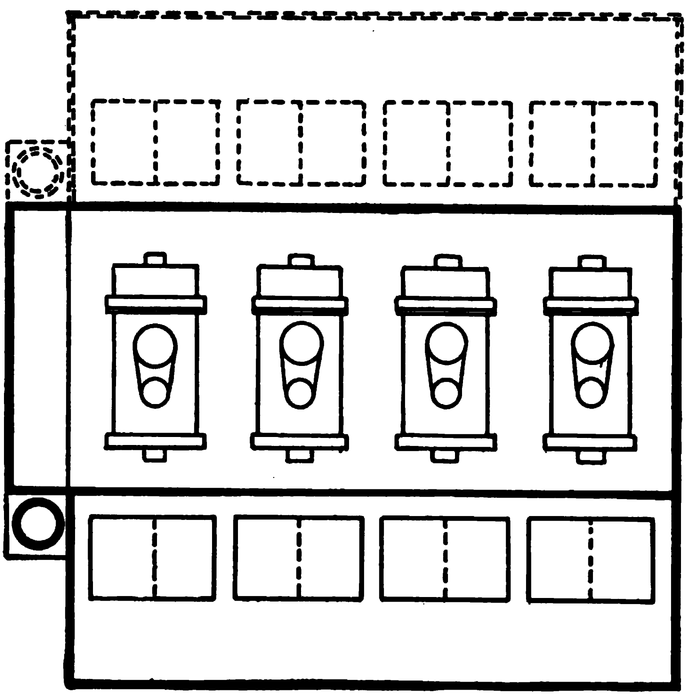


FIG. 3.

but, however, in this latter case, the smokestacks are located within the boiler house, and not as shown in Fig. 3. This arrangement of the generating room, between the two boiler rooms, is characteristic of the Frenchman's artistic taste for architectural symmetry. The disadvantage of this arrangement is that it is not mechanically sym-

metrical, though the fact may be considered that it would be practically impossible for a disaster to occur to both boiler rooms at the same time.

There are a number of power plants in which the boilers are arranged in two rows in one boiler room, with a firing aisle between; some of these are double decked, notably the Manhattan power plant in New York City, and the Chelsea plant of the London, England, Underground Railroad, while the Metropolitan Traction Company's power plant in New York City has three superimposed tiers of boilers. The arrangement of the boiler house depends entirely upon the size or capacity of the steam generating unit selected, but when units of over 10,000 square feet heating surface are selected, as in the Bow Road plant, London, it is hardly necessary to use a second tier.

With the introduction of the steam turbine a great change took place in the general arrangement of power plants; the generating room with the turbine plant being smaller than that of the reciprocating engine, owing to the turbo-generating units being much more compact, and this notwithstanding the fact that with the turbine the condensing apparatus is larger than with the reciprocating engine. Recently the most prominent plants have been built on this plan, the Carville station at Newcastle, the Fisk Street station of the Commonwealth Electric Company of Chicago, the latest Boston Edison station and the Philadelphia Rapid Transit station being important examples, while numerous others may be mentioned; viz., the St. Denis plant of Paris, France, now being erected, which will, when completed, be the largest turbine station in Europe, even exceeding the large Chelsea station in London. The layout of this type of plant is shown in Figs. 4 and 5. The marked difference in the boiler arrangement is that

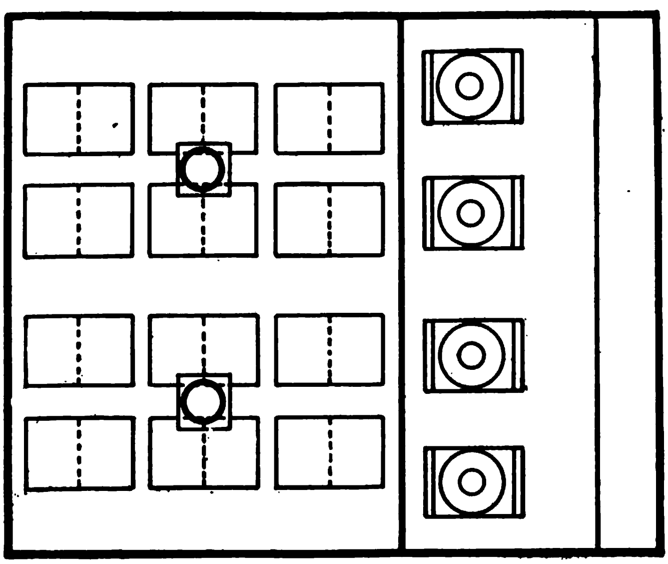


FIG. 4.

the rows of boilers do not run parallel to the generating room, but at right angles to it. In this way the power plant is divided into separate and distinct units, each row of

boilers feeding in regular operation its own particular turbine. The arrangement of the boilers in rows at right angles to the engine room is by no means a new one. In 1898 the McDonald Road Generating Station, Edinburgh, Scotland, was designed on these lines with the engine rooms side by side, and between two boiler rooms at right angles with them. The plant of the Central Electric Supply Company of London, England, is of similar arrangement; both plants were designed by Dr. Kennedy. By this arrangement the engine room can be designed with a minimum amount of floor space, but at the same time the area of the boiler room is increased over that in which two rows of boilers are placed parallel to the engine room. The fancied economy of the turbine in regard to economy of floor space occupied has not been realized in some cases, owing to the fact that the boilers have been set at right angles to the engine room; for instance, the Boston, Mass., Edison Electric Illuminating Company's power plant occupies 2.45 square feet of ground area per K.W. of generating capacity, while the Interborough (Subway) power plant in New York City, where reciprocating engines are used, with two parallel rows of boilers (notwithstanding the fact that a great deal of room has been allowed around the engines), only occupies a ground area of 2.32 square feet per K.W. In both cases the prime movers have a normal capacity of 5,000 K.W.

Where it will require three or more boilers to feed one turbo-generating unit the arrangements shown in Figs. 4 and 5 have generally been found to be advantageous, while for a less number it is advisable to follow the plan shown in Fig. 2, but this is merely a matter of opinion, as prominent engineers advocate both systems. In Fig. 5

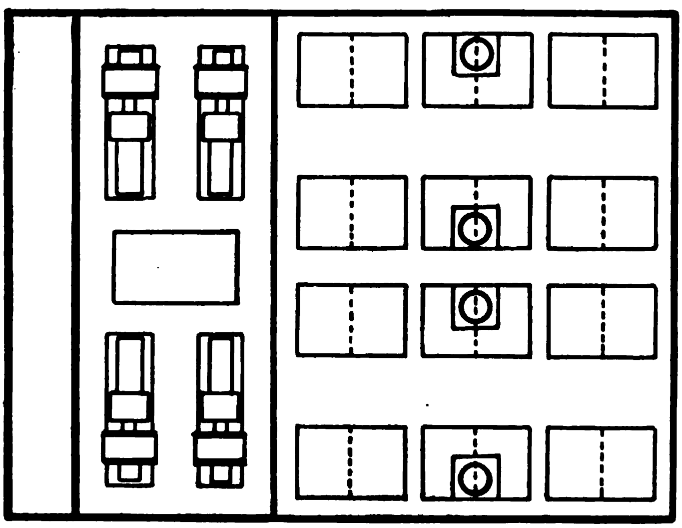


FIG. 5.

it will be seen that there are two separate firing aisles, and increasing the capacity of the plant in either direction increases their number, and with the increase of the number of firing aisles the coal-handling apparatus is likewise increased. Where the coal is

landed on a truck at the ends of the rows of boilers the liability of interruptions to the service occurring from mishaps to the conveyor is reduced. In order to avoid such interruptions in plants with a single firing aisle, it is frequently found necessary to install duplicate conveyors, either one of which is able to handle the requirements of the station. Conveyor accidents, however, will not interfere with the operation of the plant, provided the coal-storing capacity in the bunkers is sufficient to tide over the time necessary for repairs. A good example of how long a plant may be operated, should such an accident occur, is the power house of the Interborough Rapid Transit Company (Subway) of New York City. The firing aisle in this station is 693 feet long and the storage capacity in the overhead bunkers is 16,000 tons. It will be seen that a very long longitudinal conveyor is required to serve this plant; in fact, it was found necessary to cut it into two sections. In a plant of equal capacity, with four firing aisles, each could be served by a conveyor about 120 feet long, requiring less power than a longer conveyor. At the same time, if the bunker capacity provided is ample to run the plant from three to four days, and if the bunkers are kept full, this time will be ample to repair any conveyor breakdowns. In fact, one way to insure reliable service is to keep the bunkers full, but as over-long storage of coal may result in spontaneous combustion in the bunkers, judgment is required in regard to handling the supply.

Complete Unit System. — In modern stations the practice is to divide the entire plant into a series of units, as has already been mentioned, each unit comprising a prime mover and generator with its condenser and attendant auxiliary machinery, together with the requisite number of boilers. The switchboard is also divided on the same system, giving to each generator a panel provided with all the necessary instruments and switches. In many cases it is well to carry the unit system further, making it complete in all particulars, with its own boiler feed pump, feed-water heaters, economizers and chimney. There are many advantages to be gained by arranging a plant on this basis. The design of all the units being alike, new plans are not required when it is desired to extend, and the stock of spare parts is greatly reduced. Operation is more convenient, since men can be shifted from unit to unit without any confusion incident to their not being familiar with the piping system, etc.; trouble is easily localized and the affected unit cut out, and such plants are more easily supervised in operation and construction. During construction each unit can be completed and put in operation by itself, without waiting for other portions of the plant, and an operating force can be broken in rapidly on the machines in operation, thus being prepared to run the other units as fast as it is found to be necessary.

Boiler House. — The boiler house is usually arranged so that the boilers are located on one or two floors, with a basement beneath the lower boiler room. This arrangement, however, is seldom found except in the case of large plants. Such a basement is arranged for the handling of ashes, soot, the boiler feed pumps, piping, fans for forced draft, storerooms, repair shops, etc., and, occasionally, on the Continent of Europe, economizers are placed in the basement, though in British and American

practice economizers are usually placed on the floor of the boiler room, as is the case in the power plant of the Manhattan Elevated Railroad and the Chelsea plant of London, which are very similar. In these instances the economizers are placed in the rear of each of the two tiers, while in the St. Denis plant of Paris and the plant of the Glasgow Corporation the economizers are placed on a floor above the boilers. Coal bunkers above the boilers are more frequently found in British and American practice, while on the Continent a coal storage house is frequently provided at the side of the

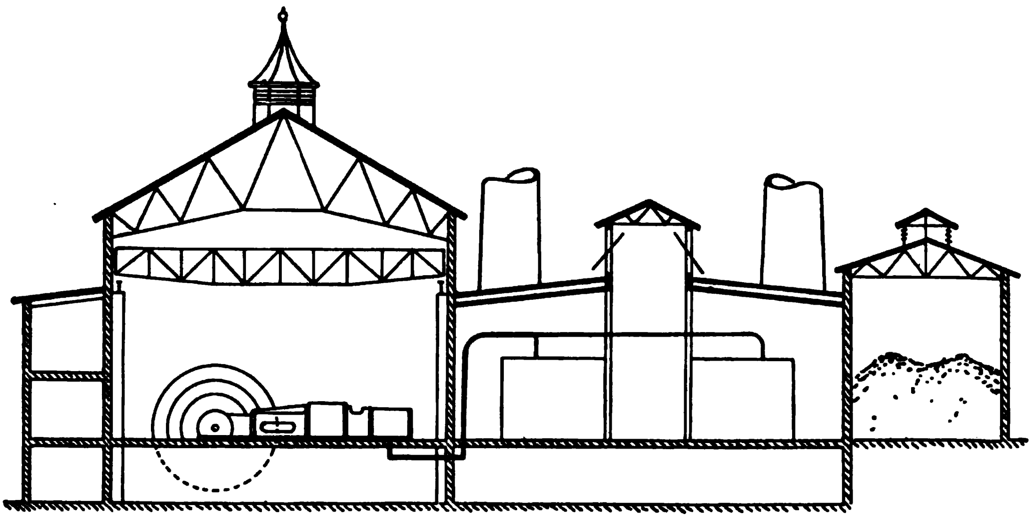


FIG. 6.

boiler house, as may be seen in Fig. 6, which shows a cross-section similar to one of the twin municipal plants of Vienna.

The smokestacks are frequently located directly in the boiler house, extending through to the basement between the boiler settings. This also is practically confined to British and American practice, for on the Continent of Europe the smokestack is frequently placed several feet away from the boiler house. This, however, may be due, to a certain extent, to the cheapness of land, but where this is very expensive it will probably pay to carry the smokestacks on the columns from which the coal bunkers are suspended, as has been done in one of the largest plants in the world — that of the New York Subway system. Here there are five 1,200-ton radial brick smokestacks, each of which is supported on six columns, which carry part of the load of the boilers and that of the coal bunkers. This same arrangement has been adopted by the New York Central and Hudson River Railroad Co. in their two stations at Yonkers and Port Morris, in the vicinity of New York City. In the above-mentioned stations there are two rows of boilers arranged on one floor with a firing aisle between, the smokestack above the firing aisle rising through the bunkers and dividing it in sections, therefore reducing the coal storage capacity. By having the firing aisles arranged so that they are at right angles to the generating room, as previously explained, and in

common use in turbine stations, each group of boilers may have its own smokestack, as is the case in the Delaware Avenue station of the Philadelphia Rapid Transit Co., Philadelphia, Pa., or two groups of boilers may have a common smokestack, as with the Fisk Street station of the Commonwealth Electric Co. of Chicago, and the Boston Edison station, diagrammatically shown in Fig. 4. In the diagram Fig. 4 it will be noted that there are three firing aisles, the center one being common to two rows of boilers and the end aisles serving a single row of boilers. Stacks common to two rows

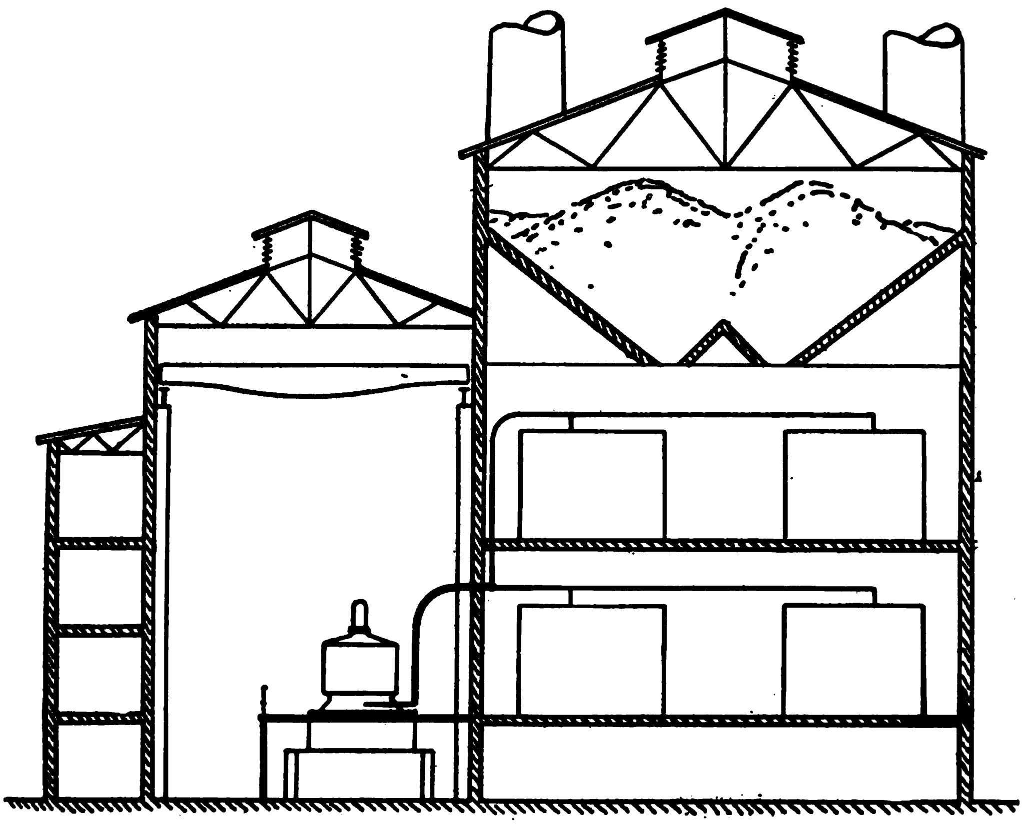


FIG. 7.

of boilers are either mounted on columns, as in the Fisk Street station in Chicago, where steel stacks are used, or extend to the ground between the boilers, as in the Boston Edison station, where radial brick stacks are used. The space between the boilers in this latter case can be utilized for the installation of economizers, should their adoption be decided upon. Fig. 5 shows an alternative layout in diagram, which differs from the above in having only two firing aisles for the same number of boilers. This diagram shows a boiler room similar to that of the Delaware Avenue plant in Philadelphia, while the turbine room is similar to that of the St. Denis plant at Paris, France. In this arrangement each row of boilers is served by a separate chimney.

In some cases this arrangement is partially adopted, the double row of boilers being served by a larger stack than the single rows. The disadvantage of this arrangement appears when it is desired to extend the plant, which becomes unsymmetrical from an architectural point of view. An example of this construction is the Detroit (Michigan) Edison Company's plant and the Marion (New Jersey) plant of the Public Service Corporation. When separate chimneys are used for each row of boilers, the appearance of the plant may be marred by the large number of chimneys required, but this arrangement lends itself to suitable architectural treatment. An advantage of this construction is that it extends the unit system further than it is usually carried, though on the score of expense the two small chimneys required for the double row of boilers cost slightly more than would a single chimney, capable of serving both rows. When the dampers, flues and other items connected with the structure are considered, however, it may easily be found that the smaller chimneys entail less expense, and the difference may be more than sufficient to make the small chimneys the less costly. The arrangement shown in Fig. 5 also reduces the number of bunkers and conveyors required below that shown in Fig. 4, but in extending the plant in the latter case an additional row of boilers can be added, and no additional bunker need be constructed, while in the former the addition of a row of boilers requires an additional bunker, with its coal conveyors.

An arrangement frequently used in Great Britain and the United States is shown in Fig. 7, and a third deck of boilers has been used in some cases. This arrangement is prohibited by law in France, where boiler houses are restricted to a single story; and

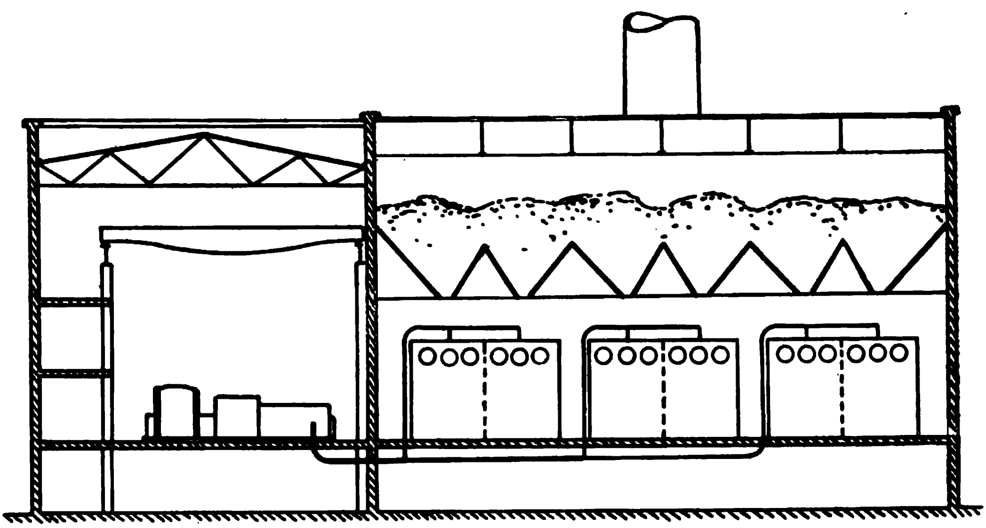


FIG 8.

elsewhere on the Continent this arrangement, although low in first cost of building, is not looked upon with favor, owing to the comparatively low cost of land. Another reason is that dynamos and engines used in these countries have not been of the enormous size of those used in America until within a recent date, when some turbo-generators of 10,000-horse-power have been put in operation.

The cross-sections shown in Figs. 7 and 8 represent, in the first case, a two-story boiler house parallel with the generator room, and in the second case a boiler room at right angles with the generator room. It will be noted that the bunker capacity in the former case is larger than in the latter, and when a single-story boiler room is used, similar to Fig. 7, the bunker capacity is retained. Fig. 8 is a cross-section of a plant, the plans of which are shown in Figs. 4 and 5, the generator room, however, being slightly different.

Boilers up to 6,500 square feet of heating surface are usually set two in a battery, while those of larger size are preferably set as individual units. The space between a pair of boilers or at the side of a battery should be at least five feet, to allow room for dusting the tubes and cleaning. The firing aisles are, of necessity, of sufficient width to permit the withdrawal of the tubes, and should be from two to three feet wider than the length of the longest tube to be handled. From six to eight feet is required above the boilers, to permit the installation of the large radius bends required in up-to-date steam-pipe construction, and to allow sufficient space for the walkways required to give access to the various valves. From a commercial standpoint it is desirable to keep the boiler room as low as possible in total height, but at the same time efficient operation cannot be attained unless sufficient space is provided to give free access to all parts of the apparatus. As an illustration of the wide difference in the views of different designers, in the Interborough power plant in New York the height of the boiler room from basement floor to the peak of the roof is 125 feet, and in the St. Denis plant at Paris this height is 65 feet. In both cases there is a basement, one floor of boilers, one economizer floor and coal bunkers. The former plant uses the regular stationary Babcock & Wilcox boiler of 6,000 square feet heating surface and the bunkers are above the economizer floor. In the French plant the marine type Babcock & Wilcox boiler is used, having 4,000 square feet of heating surface, and the coal bunker is suspended between the economizer floors or galleries.

Special attention is called to Fig. 6, which represents a typical Continental power plant, a very low boiler room, with a basement and a monitor skylight over the firing aisle, for supplying light and ventilation, and a coal storage room alongside of the boiler room, from which the coal is wheeled in cars or wheelbarrows to the firing aisle.

Engine House. — Where other considerations will permit, it is a good plan to locate the engine room on the north side of the building, and make the north slope of the roof a large skylight; south of the equator this arrangement should be reversed. The advantage of this arrangement arises from the better illumination of the room, which will be much cooler in warm weather, owing to the fact that it will not be exposed to the sun shining in the large windows. While this arrangement will add considerably to the comfort of the engine room, it will cause but a very slight addition to the unavoidable heat in the boiler room.

The engine house or generating room usually occupies a single operating floor with a basement below, having the main generating sets and exciters on the former, while the basement is best adapted to the condenser, the necessary auxiliary pumps and

piping. Also it is preferable to locate here the cables leading from the generators to the switchboard, storage batteries, etc.

In horizontal turbine plants the condensing outfit may be placed between the foundation of the turbine unit, while with the vertical turbine the turbine is frequently set directly upon the lowest floor, the condenser being placed beside it, but often serving as a base for the turbine, in which case the lower floor becomes the main operating floor (see Figs. 4 and 7), and a gallery is constructed around the generating units, there being no basement below the main operating room. Where horizontal turbines are in use care should be taken to provide large openings in the floor to facilitate the handling of condensers and auxiliaries in the basement, by a crane, — a practice which has been adopted in the Carville plant in Newcastle, the St. Denis plant, Paris, and the Chelsea plant of London. Where vertical turbines are used and a gallery provided around the generators, the auxiliaries are placed around the turbine itself, below the gallery, provision being made that the auxiliaries may be handled by the crane, and when horizontal turbines are installed similar provisions should be made. In fact it is extremely important that all the auxiliaries should be accessible, and such galleries as obstruct the use of the crane should be made in sections which can be removed when occasion arises.

The operating galleries should be designed to give access to all parts of the machinery, and it is desirable to have a gallery along the division wall at the level of the boiler floor, to which access is given by doorways; this gallery, being connected to the machine galleries by stairways, or bridges, furnishes a rapid method of getting from one machine to another, without the necessity of climbing around the intervening machines. It is also a good plan to carry this gallery across the room to the switchboard galleries, on the opposite side, at the ends, and at an intermediate point in a large plant. This gallery will, in fact, be like the bridge of a ship and supplies an elevated position whence the watch engineers can observe the entire plant.

The above-mentioned arrangement applies more particularly to vertical turbine plants. Where horizontal turbines are used, there is usually a floor in the turbine room, level with the boiler floor, and the galleries on such machines are but slightly above the floor level, in fact some very large units have no galleries whatever; for instance, the 10,000 horse-power Brown-Boveri-Parsons turbines, in the Rhenish-Westphalia power plant at Essen, Germany, which is handled entirely from the floor. When horizontal engines are used there are practically no galleries, light ornamental ladders (usually supplied by the engine builders) giving access to all points too high to be reached from the floor. With vertical engines a gallery on the division wall should be at the height of the galleries around the cylinders and connected to it by bridges. The horizontal-vertical engines are usually set in a row in the middle of the room, and the upper galleries of the machines are connected, and if desirable light bridges can be used to connect the machine galleries with the galleries around the room.

When surface condensers are to be used it is essential that means be provided for handling the condenser heads, and sufficient room must be allowed to permit the replacement of the tubes, which must be carefully handled. The auxiliary

machinery and exciters must be placed so as to secure short pipe runs, and at the same time be so located that there is enough room to permit all parts to be properly looked after in operation, without exposing the men to the danger of being caught by parts in motion. Guard rails should be provided at all dangerous points.

It is a good plan to arrange the plant so that the necessary cables and steam pipes do not cross each other; that is, the conductors from the generators should leave the machines on the side away from the boiler room, and the condensers and their pumps should preferably be located where they do not interfere in any way with the layout of the duct lines; all steam and exhaust pipes being kept, so far as possible, below the floor, in order that the general appearance of the room may not be spoiled.

In the most modern plants the practice is to install a central oiling system. When this is done it is advisable to place the filters, storage and pressure tanks, together with the pumps (when gravity tanks are not used), in a separate room of fireproof construction, the only connection to the main plant being by means of the piping. In some cases this precaution is entirely neglected, and in other cases only the main storage tanks are located outside: the pressure tanks and filters being located in the operating room, or on the roof when gravity tanks are employed.

In placing the machinery a great deal of study is required in order that the room may be utilized to the best advantage, without overcrowding. Plenty of room is desirable, but at the same time where land is costly it is desirable to use it all to the best advantage without waste. This principle has been closely studied in Great Britain and the United States, while in Continental Europe a great deal of room is frequently wasted, owing to the manner in which the machines are located; this, however, is due to the fact that land values are not so important.

In the plants and arrangements above mentioned the condensers were located either in the basement or on the main operating floor. There are, however, some plants in existence in which a separate building or room is provided for the condensers and their pumps; the plant of the Glasgow, Scotland, Corporation Tramways, for instance. In this plant, vertical three-cylinder compound engines are employed and surface condensers are used. The main units are set close together, and in order to keep down the width of the engine room, where a heavy crane was required, the condensers were placed in a separate room, parallel with the engine room, where they were covered by a short span crane of smaller capacity. This makes it very easy to look after the condensers, but is not economical in the ground area occupied. In some cases a central condensing plant, of the barometric or injector type, is employed; the practice being in such cases to install the condenser outside the building, while the pumps serving it are inside. These condensers are supported by a skeleton steel frame and the exhaust pipes from a number of engines (often at a considerable distance) are led to them.

Cooling towers are of two types, forced and natural draft, and the location of the former can be made to suit local conditions, but the latter must be so situated that it is not sheltered or protected by adjacent buildings. Cooling basins or ponds are also employed, in which the water is sprayed into the pond by a number of jets. Apparatus of this character is used where the quantity of circulating water required for the con-

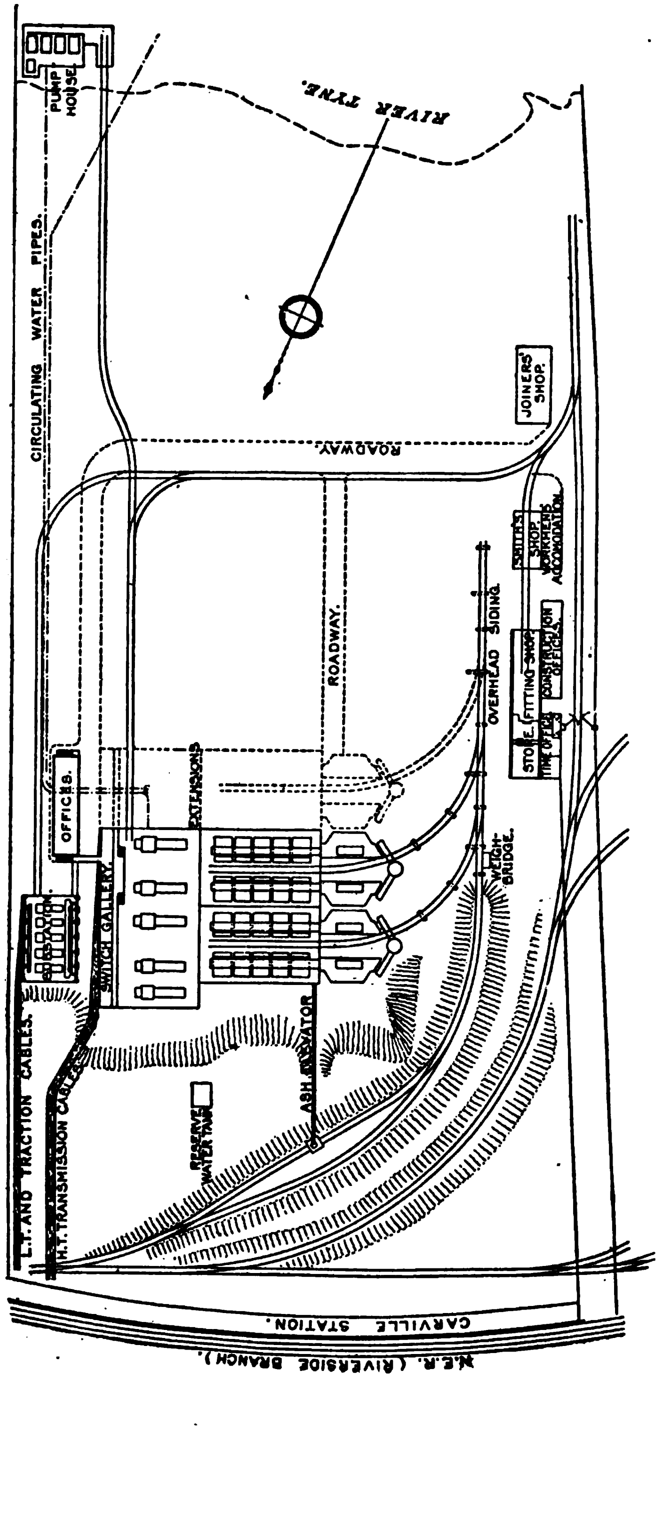


FIG. 9. Location and General Arrangement, Carville Plant, Newcastle upon Tyne. (*Inst. Elect. Engrs.*)

densers is larger than can be obtained from local sources of supply at reasonable cost. Small towers are sometimes located on the roof of the building, and the water circulates through the condenser by gravity and is returned to the tower by the pump. Forced draft towers are provided with a small shed in which the motor for driving the fan is sheltered.

Switching Room.—Another important consideration in power plant design is that of the switchboard. In large power houses an annex to the generating room for switching and measuring purposes may be very convenient, but where this space is not available a part of the generating room may be used, care being taken not to locate the switchboard on the boiler-house side of the plant, the high-tension lines and steam pipes being liable to interfere with each other. Both should be carried under the engine-room floor and kept well apart. In plants of smaller capacity the end wall of the generating room is usually large enough to accommodate the bus-bars and switching system, which when possible are placed there, as is the case with the five stations of the street railway system of the City of Hamburg, Germany, but with plants of larger capacity, when this space is seldom large enough to accommodate the bus-bar and switching system, a space at the side of the generating room may be utilized for this purpose. The main bus-bars may be located below the floor level of the engine room, but the controlling switches should preferably be placed in the gallery, from which the generating room is easily overlooked. The Elevated Railroad power house at East 74th Street, the Subway Railroad power house at West 59th Street, both of New York City, the Chelsea plant in London, and the Carville plant in New-castle, England, all have their switchboards arranged in this manner. The end wall may even be utilized for switchboard purposes in the larger plants by building it in several tiers. This has been done in the Waterside station, No. 1 of the New York Edison Company. Figs. 6 and 7 show a station with an annex built for switching purposes. This annex may run the entire length of the building, as is the case with the Public Service Corporation of New Jersey, and the Potomac Electric Power Company of Washington, D.C., while the St. Denis plant of Paris, and the twin municipal plant of Vienna have their annex constructed along the lines of that shown in Figs. 5 and 6.

Care should be used to avoid crowding of the switching compartment. Frequently this branch of power plant design is considered of small importance; this, however, is an entirely mistaken idea; on the contrary, the switching room with its wiring system may be said to be the pulse of the entire electrical equipment, just as the steam-pipe system is that of the mechanical equipment. The crowding of the switching apparatus into a corner of the power plant can only be looked upon as poor policy. The Swiss, usually acknowledged leaders in switchboard installation, give us examples of where the floor space occupied by the switching room is more than that of the generating room itself. The Swiss plants, however, are usually hydraulic plants, and an example may here be of interest. The switching house of the plant "Obermatt," of the City of Lucerne, covers an area of almost three-quarters of the generating room, but as the

switching house occupies three floors, the floor space is more than twice that of the generating room.

In speaking of the generating room, the floor or ground area occupied alone has been considered, the height being dependent upon architectural considerations and the type of machinery used. Horizontal engines and turbines can be installed within a low building, while vertical engines and turbines require a higher roof. The height of the boiler room has already been mentioned; for architectural reasons the engine room is frequently made of equal height, although by so doing the cost of the walls and steel framing is considerably increased. From an engineering standpoint the height of the engine room is fixed by the height required under the crane to handle the machinery.

Coal Storage Plant. —As has been stated in a previous chapter an additional storage capacity for coal should be provided besides the bunkers above the boilers, as they are of comparatively small capacity, when the output of the plant is taken into consideration.

Strikes, either at the mines or the transportation companies, are liable to occur at any time, so it is often considered advisable to arrange for capacity enough to carry the plant several weeks. It is advisable also that this coal storage plant should be placed as near to the power station as is possible, and a suitable method for conveying the coal from the piles to the bunkers be provided. The cars may run on trestles at the side of the boiler house, and dump the coal directly on the ground beneath the trestle where it is stored, or the cars may be dumped in hoppers from which it is conveyed and deposited in coal piles, a similar system being used where the coal is unloaded from barges and conveyed to its storage. It is customary in American and British practice to provide for the coal storage capacity in the bunkers beneath the boiler-house roof; while on the Continent of Europe a separate building is provided. It can be easily seen that the storage capacity of the bunkers is limited, and in order that capacity enough to last some time shall be had the usual American practice is to dump the coal in an open field where it is possible to do so. This has been necessitated by the size of American plants, while in European plants capacity enough to run the plants several weeks is easily obtainable in buildings, which are built by the side of the boiler house, as illustrated in Fig. 6, though there are some cases where the coal is stored in the open at the side of the boiler house.

Auxiliary Buildings. — Under auxiliary buildings we may consider those buildings which are necessary to facilitate the successful operation of the plant, consisting of offices, repair shops, storehouses and pumping stations, while in cases where the plant is situated in the country, residences are provided for the superintendent of the plant and the main operating force. This practice, however, is practically confined to Europe, while in America all of the machinery is generally placed under one roof, and as the large plants are in or near the cities the operating force may live in the immediate neighborhood. The arrangement of the auxiliary buildings of two European plants may here be of interest. The site of the Carville power station in Newcastle, Eng-

land, banked on one side by the river Tyne, and on the other by the railroad from which sidings run directly to the plant, has upon it a number of auxiliary buildings, such as pump house, office building, a store and fitting shop, blacksmith shop and accommodation for workmen, a special construction office and joiners or carpenters shop, while a special reserve water tank and a sub-station are also on the same plot. The tracks from the railroad are so arranged that a car may be run directly to any of the prominent buildings (see Fig. 9).

The twin municipal plant of Vienna is situated on a plot by the Danube Canal, the siding from the railway running directly between the two plants (see Chapter X). Situated on the plot near the main buildings are two pumping stations, one large and one small, three pumping pits, a reservoir, an office building, residence for the superintendent and one for the main operating force, and, as the plant is situated outside the city, there is a canteen for the working force. The entire plant is surrounded by grass plots with graveled walks and a number of shade trees have been set out, not only with the idea of beautifying the surroundings of the plant, but to serve a utilitarian purpose in preventing the dust which would otherwise be swept into the plant were the earth bare. The plant is also surrounded by a high picket fence.

COAL STORAGE.*

Introductory.—The fuel question is one of the live subjects before the power plant manager; the plant cannot run without fuel and the cost of this is the largest single item in the operating account. The cost of the coal per ton, as taken from the bill, is not the total cost of that amount of coal, for this only includes its delivery in cars or boats at the power plant, where it has to be unloaded, conveyed to the fire room, placed on the grate and the ashes removed from the building and disposed of.

The quantity of coal burned is from ten to twenty-five times the weight of the resulting ashes, and for this reason proximity to a point where coal can be secured with the minimum amount of handling is of more importance than ability to dispose of the ashes. In any event it is desirable to avoid carting either coal or ashes, since such procedure means additional handling and its attendant expense.

As plants increase in size the importance of a reserve supply of coal becomes more and more evident; for the small plant whose consumption is limited to five or ten tons of coal per day, one or two carloads is often considered a big supply on hand, while in the plant whose daily requirements run from six hundred to a thousand tons, a large reserve is necessary.

The uncertainty of the coal supply is due to many causes, strikes in the mines of from a few days' to a number of months' duration have often occurred; and in some cases these labor troubles have been sufficient in magnitude practically to stop the mining of coal. All transportation service is subject to interruptions of a more or less serious character from storms, floods and strikes; these last, however, have not been frequent in late years, but a number of railroads have had considerable trouble with

* See author's original article in *Power*, April, 1907.

freight handlers in some localities. Where railroads are depended upon for coal supplies, the first sign of labor troubles at the mines is the signal for them to seize all the coal in transit on their rails, and until their own stores are filled to the limit there is little chance for an outsider to secure any quantity of coal.

Since, except in a few instances, it is impossible for the coal consumer to have absolute control of his supply from the mine to the fire room, it is absolutely necessary to

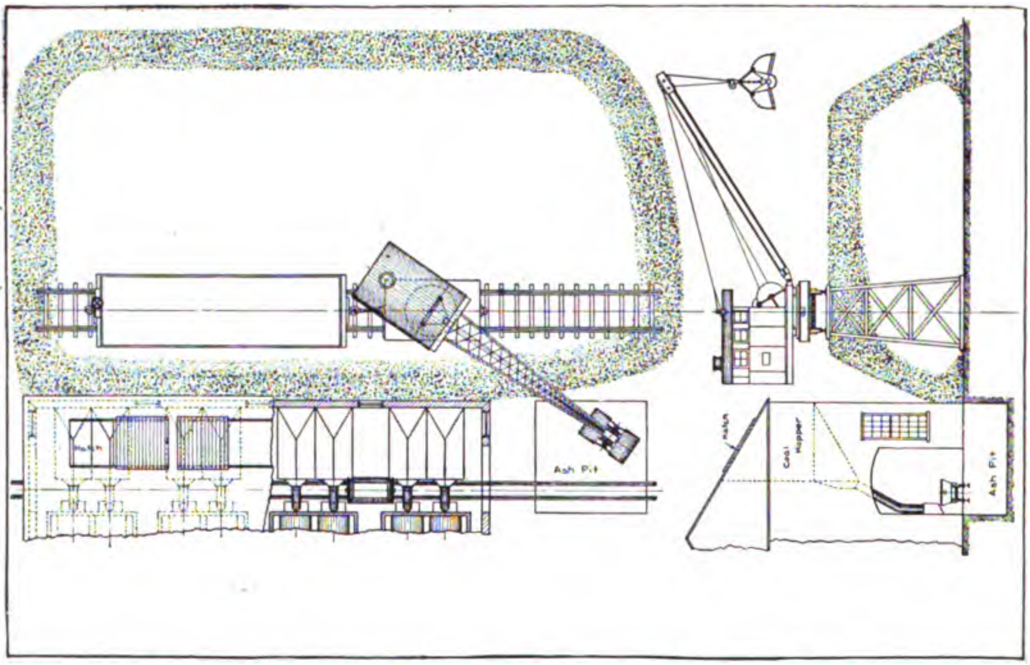


FIG. 1. Coal and Ash Handling Scheme with Browning Travelling Crane.

adopt such measures as will protect his interest during all contingencies, and the only method by which continuity of plant operation can be insured under all circumstances is by the establishment of a coal storage plant of sufficient size to carry the plant over any stoppage in the receipt of coal.

In some plants the coal bunkers alone are depended upon as a reserve, while in other cases they have been augmented by storage plants designed for the purpose. A fuel storage plant of any magnitude involves a considerable investment in machinery, and in addition a large amount of money is tied up in the coal pile. The interest on this money and the operating costs of the plant add continually to the fuel bill, but to offset this the insurance value of the plant in times of trouble is beyond computation.

Exposed Coal Piles. — Most coal storage plants have the piles exposed to the weather, and for practical reasons it is essential that a portion, if not all, of the daily supply be handled, in order to keep the machinery in shape, and for other reasons, as will appear below. Coal stored in the open or under cover loses a portion of its heating value, this

loss, in fact, being due to slow chemical changes which start as soon as coal is exposed in the breast at the mine and continue until it is burned. These losses are greatest with bituminous coals; the anthracite coals depreciate less rapidly. The losses are

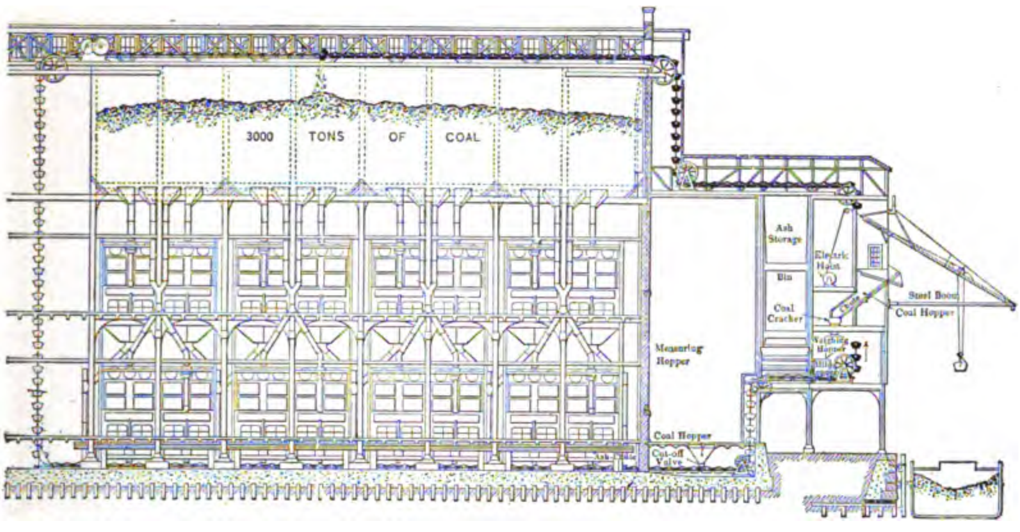


FIG. 2. Coal and Ash Handling System, the Rhode Island Suburban Railway, Providence.

higher in warm weather and in the tropics, and are due in part to the coal giving up its gases, which in some cases have a considerable thermal value. These losses are slight when the coal is fresh, but increase rapidly as the coal ages.

Spontaneous Combustion. — Coal pile fires are not of infrequent occurrence, although it is very rare that they are chronicled. Their cause is somewhat obscure, but they occur more frequently in bituminous coal which contains considerable sulphur, in the form of iron pyrites, though all coals of a friable nature are liable to spontaneous combustion. There is considerable difference of opinion in regard to the cause; moisture is by some considered to retard ignition, but wet coal in compact masses has been known to fire spontaneously. Ventilation sufficient to evaporate the water and keep the heat of the pile down is probably the best method of overcoming such trouble, but restricted or insufficient ventilation is liable to increase the trouble. Such fires are just as liable to occur in coal stored under cover as in the open, but wet coal containing considerable pyrites will ignite if stored long enough to allow of heating. Such fires are discoverable by the odor of the gases, and difficulty in breathing at such portions of the pile and by the heating of the coal. This last can be tested by driving pipes, down which thermometers can be lowered and the temperature taken, or in winter by snow melting on the pile. It is impossible to fight such fires by water, unless the whole pile can be flooded and the entire air supply cut off in this way, because the fire cokes the coal adjacent to it previous to its burning, forming a roof which sheds the water, most of which is usually evaporated before it gets so far down in the pile.

Pointed perforated iron pipes can be driven into the pile, and water forced to the fire through them, but the most complete method is to remove the coal over the fire and then attack it.

Another trouble with exposed coal piles and railroad shipments occurs in winter when the coal often arrives frozen solid in the car, and the unloading tracks must be equipped with steam pipes and outlets for thawing purposes.

From the above it may be seen that the storage question is not simple, and must be handled with a full understanding of the many trials and tribulations that ensue.

Character of Storage Plant. — The general arrangement and the plan required for coal storage depend upon local conditions, and the concerns building this class of machinery are prepared to submit designs for plants of any desired capacity, when they are furnished with ground plans showing the area to be covered and its contour. Some plants require level ground or expensive grading, while other machines can be installed with but a slight amount of grading. The character of the plant will depend in part upon the method by which the coal is received and delivered; in some places cars alone are received, in others, boat coal only, and occasionally both methods are available. Coal is also transported to the power plant by conveyors and in notable instances it must be reloaded in barges to reach the power house.

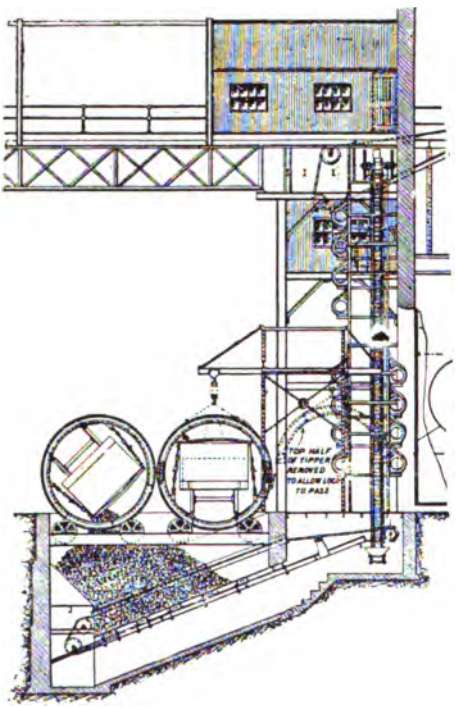


FIG. 3. Coal Conveying System, Willisden Plant, London.

In Continental plants the coal storage is generally located alongside the boiler house and is usually covered, or roofed in, and the coal is brought into the firing room by small cars. But in a few of the recent plants American practices have been followed, overhead bunkers and conveyors being introduced and the coal spouted down to the boilers.

Description of Various Storage Plants. — The coal storage plant of the Edison Electric Illuminating Co. of Boston, Mass., presents a very interesting method of treatment. At this plant the fuel is delivered in large barges, carrying over 1,000 tons each, and two channels have been dredged out and wharves built, on both sides of which the barges can be moored. On the wharf are mounted two unloading towers, a small one installed at the time the original power station was built, and a second tower added at the time the turbine station was built. There is room for an additional coal tower

on the pier, which will be added when the extension of the station necessitates such addition to the handling capacity. The first tower requires two operators, and is equipped with a one-ton bucket, making one trip per minute. The second tower

FIG. 4. "Brownhoist" Gantry Crane with Cantilever Extension at the L Street Plant, Boston.

requires but one operator, and can unload from either side of the pier; it is equipped with a one and one-half ton grab-bucket which can make three trips per minute.

The coal is transported to the coal storage yard by Robins belt conveyors, being deposited along one side of the yard from the conveyor trestle. The storage yard is covered by a bridge tramway, which distributes the coal over the yard or redeposits it on the conveyor, which can be reversed for transporting the coal to the bunkers. The storage capacity of this plant is about 100,000 tons of coal.

The New York Edison Company has a storage plant at Shadyside, N.J., as previously mentioned, where facilities are provided for the storing of 50,000 tons of bituminous coal and 100,000 tons of anthracite. This arrangement is peculiar, owing to the fact that the storage yard is located a considerable distance from any power plant of this company, the reason being that New York City ground is too expensive for this purpose, and likewise because railroad connections could not be made to any of the plants. The site chosen for the storage plant permits of connection with

several railroads, and arrangements are made by which anthracite coal can be received either by car or by boat. The bituminous coal is received entirely by boat,

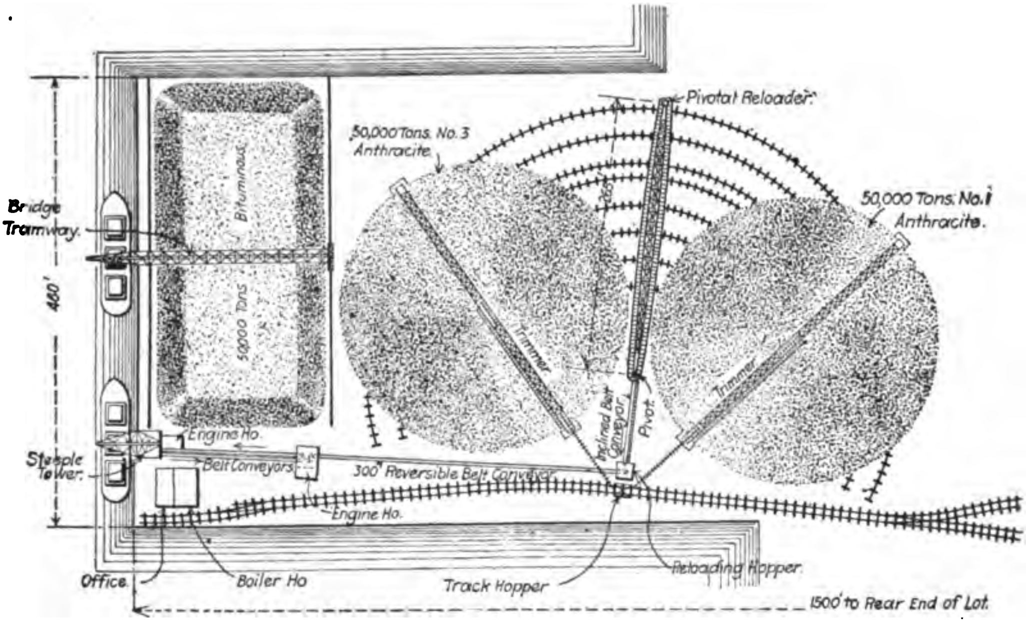


FIG. 5. Plan of the New Coal Storage Plant of the New York Edison Company at Shadyside, N.J.

and both kinds of coal must be reloaded into boats for transportation to the stations of the company in New York City. This plant was designed by the Dodge Coal Storage Company of Philadelphia, Pa.

The bituminous pile is covered by a traversing bridge equipped with a two-ton clam-

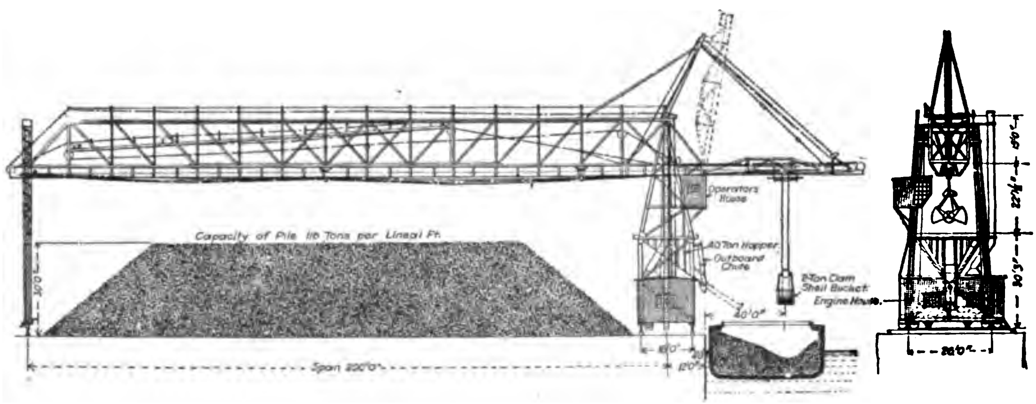


FIG. 6. Dodge Traversing Gantry Bridge, Coal Storage Plant at Shady Side, New York (*Engineering Record*).

shell bucket, which unloads from boats to the pile or from the pile to boats, the front tower in which the operator is stationed being provided with suitable loading chutes.

Anthracite coal can be unloaded from boats by a steeple tower with a one and one-half ton grab-bucket, which delivers to a reversible belt conveyor, by which the coal is transported to a hopper, whence it passes to the trimming bridges spanning the piles. Railroad coal is dumped into a track hopper from which it passes to the trimmers. The anthracite piles are of the well-known Dodge circular type, and a reloading sweep traveling on semicircular tracks is used for taking the coal from the piles to a hopper, through which it reaches the belt conveyor leading to the steeple tower, which is equipped with a chute for loading boats. Five-ton weighing hoppers, in duplicate,

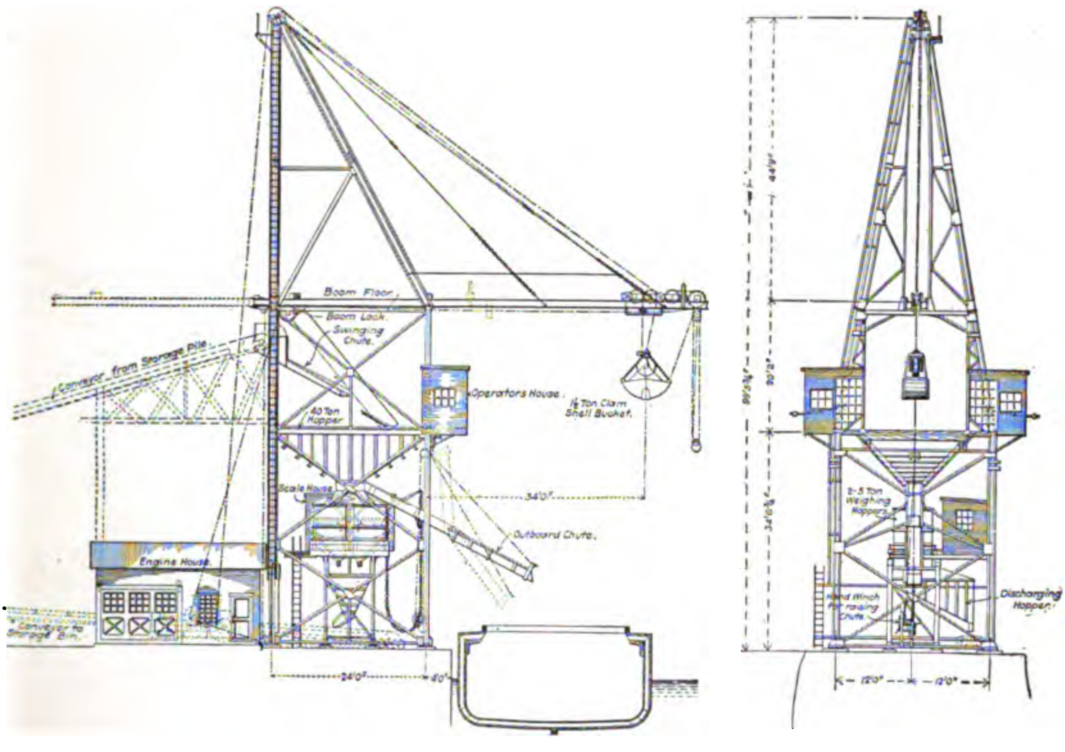


FIG 7. Steeple Loading and Unloading Tower with Weighing Hopper, Shady Side Coal Storage Plant of the New York Edison Co. (*Engineering Record*).

are provided in the towers, by which all coal can be weighed upon its receipt and shipment.

The accompanying illustrations will serve to give a very comprehensive idea of this coal storage plant.

At the plant of the Metropolitan Electric Supply Company, London, England, a coal hopper has been built below the track on which coal is received. Over this hopper is placed a Bennis rotary tipping device in which the coal cars, after being clamped, can be turned completely over, the coal falling into the hopper, from which conveyors transport it to the bunker in the boiler room (see Fig. 3).

On the Continent of Europe a great deal of hand labor is employed in coaling plants; for instance, at the Barmbeck plant, Hamburg, Germany, the coal is received in barges, and is shoveled into buckets; these have a trolley attached to the bail and are lifted from the barge by a traveling revolving crane or "whirley," which places the trolley on an inclined track, down which it runs into the storeroom, dumping at a determined

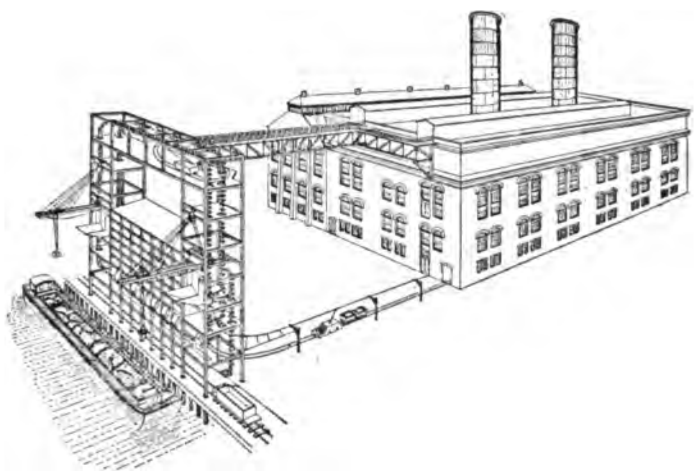


FIG. 8. Coal and Ash Handling System, Williamsburg Plant, Brooklyn.

point and passing on around the loop, and back to a point where it can be reached by the crane. There are six of these loops alongside of each other, and the crane can take or place buckets on any one of them. The storage capacity is about 6,000 tons. The coal is loaded by hand in three-wheeled cars, by which it is taken to the fire room, and is shoveled from the car into the furnace.

A novel system, involving much hand labor, both in the receipt of coal and in firing with its attendant expense, is exemplified by the Vienna twin municipal plant in Austria. The coal is brought in by cars on a railroad siding running between the two plants; these are passed over a scale and are weighed; they are then placed on a transfer table by means of which they are transported laterally to either of the two plants. From the transfer table the cars pass to tracks leading to elevators, by which they are raised to tracks passing over the coal bins, twenty-five feet above the bottom of the bins, which are on a level with the boiler floor. The coal is deposited in these bins according to its quality, and from them is loaded into small cars by hand for transfer to the fire room, and is shoveled from these cars into the furnaces.

In some plants on the Continent the conveyor system, so much used in America, has been introduced, overhead bunkers, ash and coal conveyors being installed. The motive power for such machinery is electricity in all cases.

A large part of the difference between American and European coal-handling practice arises from the different capacities of the railroad cars in use. European cars rarely exceed twenty tons in capacity, while in America forty and fifty ton cars are used.

Comparison of Various Systems. — There are a few of the European coal-handling systems which are seldom found in connection with American power plants. In the latter the coal is usually conveyed by the chain-bucket system, and in some instances by belt conveyors. This is largely due to the layout and construction of the building, for in

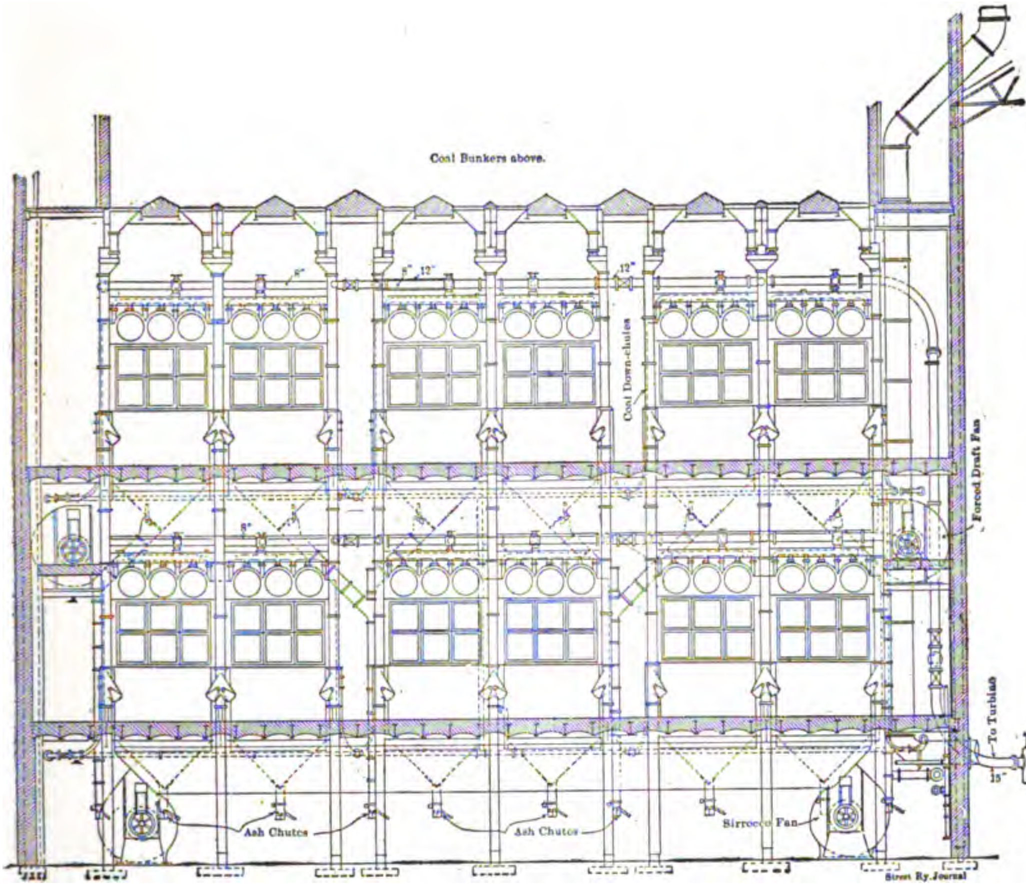


FIG. 9. Longitudinal Section of Boiler Room, Williamsburg Plant, Brooklyn, showing Coal and Ash Chutes.

the European plants the cost of land is comparatively small, the buildings are low and the coal bunkers are provided at the side, while in America, where the land is much more expensive, the buildings are designed higher with the bunkers on top. However, in connection with recently constructed prominent plants, as the Chelsea power plant of London, the St. Denis plant of Paris,* and the power plant of the Berlin Subway and Elevated Road, belt and bucket conveyors have been employed, and without doubt in the design of future power plants in Europe the overhead bunker will be much more used, whether mechanical stokers are installed, or whether the old method of hand firing be adhered to. This will naturally cause a more common use of the conveyor system. The ques-

* *Power*, February, 1907, St. Denis Power Plant, Franz Koester.

tion still remains, however, as to whether they will convey the coal in small quantities or in greater bulk, similar to that at the above-mentioned Vienna plant, where the whole coal car is hoisted and dumped into the bunkers. This may be done far more readily in Europe than in America, as there the capacity of the cars is smaller than those used in America as mentioned above. Here, as well as abroad, the tendency toward conveying coal in large quantities is very noticeable, as, for instance, in the Mead-Morrison coal-handling system at the Gould Street power house, Baltimore, where the coal is hoisted by a 25 horse-power steam engine up an inclined structure in buckets of one-ton capacity, and dumped into a hopper in the tower, after it has passed the crusher at the base, operated by a 15 horse-power motor. From here it is dropped into cars operated by cables from a 10 horse-power motor. Another prominent system worthy of attention is that at the Long Island City Railway power plant, where the coal is hoisted in grab-buckets of one and one-half ton capacity to a height of about 160 feet, where it is dumped into a hopper supplying the crusher, whence it falls into the cars of a cable road which bring the coal to the top of the bunkers in the power house.

In some plants, noticeably that of the Interborough Rapid Transit Co. of New York (Subway), the coal handling is accomplished entirely by belt conveyors, *i.e.*, after the coal has passed the crusher at the coaling tower it is brought on belt conveyors to the side of the power house, during which course it is transferred to a second belt conveyor. It is then raised by a series of belt conveyors to the top of the bunker, some 100 feet above the boiler-room floor, during which journey it is transferred four or five times, as there are two longitudinal belt conveyor systems at the top of the bunker. It will be seen that as each conveyor must be operated by a separate motor the liability of breakdown is materially increased, as of course the failure of one piece of apparatus means the disabling of the entire system. In considering this installation the question immediately arises as to why a vertical bucket system or a system similar to that at the Long Island City plant was not employed. As this belt conveyor system occupies the entire end wall of the boiler room, the vertical system would have saved not only a large amount of space, but would also have materially decreased the operating cost. Further, it is claimed by various authorities that the entire coal-handling plant of the Long Island City station, has been installed for a small fraction of the cost of the above-described cross-belt conveyor system. Of course it must be admitted that the belt conveyor may have some advantages, especially on small elevations; however, where side runs are necessary enormous space is required, an additional example of which is found in the new Boston Edison power station. Another disadvantage of the belt conveyor system is that the belt cannot handle the ashes as they come out of the ash hopper of the boilers, if they are red hot, as they usually are. This is a serious point in view of the common practice of utilizing the same conveying apparatus for the handling of both coal and ashes.

Overhead Bunkers. — Overhead bunkers are usually found when the plant is located on expensive land, and such plants are usually far above the average in bunker capacity, which ranges from five to thirty-five tons per lineal foot.

These bunkers are composed of a steel framing, supporting concrete or reinforced concrete flooring, upon which the coal lies. The bottom of the bunker slopes usually at an angle of 45° and forms a series of pockets with inverted "V"-shaped division slopes, the coal chutes being attached to the bottom of these pockets. For a double row of boilers the cross-section of bunker is like a "W," the outside sometimes being carried up vertically to give added depth when the spread is carried to the rear boiler columns. In some bunkers the floor slopes are made very flat, but it is not advisable to use a slope less than the angle of repose of coal, 27° for anthracite and 35° for bituminous, for under ordinary conditions such bunkers will be self-clearing. Convenience in framing, however, makes the 45° slope more desirable, and gives an added factor to the self-clearing properties of the bunker, though under unfavorable conditions, particularly after bunker fires have occurred, it may be necessary to send men into the bunker. The angle of repose above mentioned is the natural slope taken by the coal, and it may be of use in estimating the capacity of coal piles and bunkers when the coal extends above their top in the pile.

In a few plants the mistake has been made of using such a flat-bottomed bunker that hand labor is necessary to shovel the coal over the spouts. Such bunkers are dangerous and frequent fires occur in them. Another type is the suspended bunker of plate steel construction. Plate steel bunkers usually run from five to ten tons per lineal foot, while masonry bunkers run as high as thirty to thirty-five ton capacity per running foot.

The use of bunkers is essential to proper utilization of mechanical stokers, in which the feed hoppers are usually too high to permit of the coal being fed to them conveniently by hand. In existing plants, when mechanical stokers are installed, a small coal pocket suspended from the front boiler columns or the roof trusses is sometimes provided for each boiler, and in other cases a continuous steel pocket is put in.

The openings in the bottom of the bunkers may be provided with cut-off gates; with steel plate construction the gate frames can be secured to it, but in concrete bunkers it is desirable to provide a casting at the throat of the pocket, which will resist the cutting action of the moving coal, and furnishes a convenient point of attachment for chutes or gates.

In some cases the chutes are bolted directly to the bunker casting with a cut-off gate in it, while in other cases a small receiving hopper loosely suspended from the bunker or the steel frame of the building, or a weighing hopper, may be placed at this point. The coal spouts lead down from these hoppers. Sloping spouts are preferable to those in a vertical position, as the coal has a tendency to hang in vertical pipes and considerable ramming is often necessary to start it running. In some cases the weight of coal in these spouts is found by experiment, and an endeavor is made to keep track of coal consumption by counting the number of times the spout is filled.

The spouts are usually of cast iron of from twelve to eighteen inches in diameter; square sections have been occasionally used, for the reason that the coal does not hang in such spouts so readily as it does in those of circular section. When over-feed stokers are used a spreader-apron is required on the lower part of the spout, or else a

hinge is arranged so that the coal can be spread by swinging the spout laterally. It is also necessary to hinge the spouts so that they can be drawn back out of the way when repairs are to be made to the boiler.

In some plants a traveling hopper with chute is installed, having a capacity depending upon the design of the plant, in which the coal is received from the bunkers and distributed to the boilers as required. This hopper can be arranged with scales by which accurate account can be kept of the fuel consumption.

Bunker Fires.—Fires are not infrequent in overhead bunkers, owing to their being exposed below to the heat of the boiler room, and also because coal is frequently stored when wet. Provision has been made in a number of plants by overhead water lines for fighting such fires, but experience proves that water is a poor method of combating them, as they are usually in the lower part of the bunker, and water reaches everything but the fire. Steam can be injected into the bottom of the bunkers through the gates, or, as fires may occur with considerable frequency, it might be desirable to install a special pipe system to smother same. The best method, however, to control a bunker fire in the shortest possible time is to empty the particular bunker through the spouts and attack the fire at the boiler-room floor. Where the coal-handling facilities are such as to allow of distributing the coal throughout a number of boilers, it might be well immediately to convey the coal which is on fire to the boilers and have it burned up as rapidly as possible. While this method may seem radical and may mean a considerable loss in coal it is, in the writer's opinion, the best method of procedure, as the loss entailed would be but a very small item compared to what it would be were the fire allowed to gain a headway and spread over the entire supply.

CONDENSER WATER SUPPLY.

Inlet and Outlet Tunnels. — The large modern power plant is always equipped with condensing apparatus, owing to the greater economy secured by using steam with greater expansion. The amount of circulating water required to condense a given quantity of steam varies according to the initial temperature of the circulating water, and its permissible rise in temperature. For moderate vacua the weight of condensing water is from 20 to 30 times that of the steam to be condensed, whereas for high vacuum work with surface-condensers it runs up to 60 or 80 times the weight of the steam.

Owing to the great quantity of water required for condensing, an independent supply is necessary for this purpose, since it would not be practicable to draw such a large amount of water from the city mains. In plants located where salt water is available it is used in the condensers, and where located in the interior, on fresh waters, the unfiltered river water is used. This water is drawn in through an intake which is generally constructed of concrete, or reinforced concrete, but occasionally of iron pipes, and in some rare cases wooden flumes of considerable length have been erected.

Screen Chamber. — As this water is always liable to contain floating débris of various kinds, or ice, a rack should be provided across the mouth of the intake. This is preferably constructed of wide oak slats, or flat iron bars placed side by side. The opening between the bars should not exceed one inch, and sufficient area must be provided to permit a maximum flow with a moderate velocity, in order that the surface of the rack can be raked clean with the least trouble, and also to provide for the blocking up of considerable area. Inside of this rack an additional screen with fine meshes should be placed. This latter is preferably double and in sections, so that any part of the sections can be removed and cleaned while the others are in operation. This screen is usually a heavy timber frame, across which copper wires are strung at right angles to each other, or in some cases galvanized iron wire has been used. This latter material, however, is liable to deteriorate very quickly, owing to the galvanized surface being cracked in bending the wires.

Shut-off Gates. — It is advisable to provide shut-off gates, either to be inserted in the grooves over the wire screens or immediately back of the outer rack. These gates are necessary to shut off the water when the intake tunnel must be cleaned out. When these shut-off gates are of considerable size it is necessary to provide a by-pass in them in order that the water pressure may be equalized on both sides of the gate, thus reducing, to a large extent, the power required to raise them. This intake head should be compactly arranged in order to secure economy of construction, and either a light structure should be erected over it on which chain block hoists and trolley can be installed to handle the gates and screens, or if power-operated machinery is put in for this purpose it is desirable to erect a regular gatehouse.

Area of Tunnels and Screens. — The pump suctions should be laid from recesses or pits in the side of the intake, out of the direct current, because the large pipes required for this purpose would block up the flow of water.

The sectional area of the tunnel should be proportioned to supply the maximum requirements of the plant at a velocity not to exceed 5 to 6 feet per second, depending somewhat on the construction of the conduit tunnel. The intake rack should be provided for a velocity of about 2½ feet per second, or about 50 per cent excess area over that of the tunnel. In some cases higher velocities than above mentioned have been used, but such a practice is not advisable, as it reduces the efficiency of the pumping machinery, or, in other words, increases the amount of power required to handle the water.

Arrangement of Tunnels. — The intake tunnel should be located at a sufficient depth to secure water at the lowest stage of the tide, or the lowest water level of the river. Where possible the outlet tunnel should be on the same level, in order to take advantage of the siphon action which will be set up when the current through the condenser has been established. With this construction the circulating pump is only required to overcome the friction of the water through the condenser and pipes, and the

power consumption is reduced to a minimum. Owing to local conditions it is in many cases impossible to adopt this design, and for such cases the outlet tunnel should be above the intake, in order to reduce the amount of excavation required for the two tunnels, the inlet and discharge pits from the condenser being brought down on the sides of the conduits. The mouth of the outlet tunnel should lie at some distance from the intake, preferably in the direction in which the current of the stream flows, and the farther they are separated the better, in order that the outlet water may not be drawn back to the intake, as this might reduce the efficiency of the condensers considerably.

Scarcity of Condenser Water.— In many localities it is difficult to secure a sufficient supply of water for condensing purposes, and for such plants it is necessary to use the circulating water over and over again. There are several methods in service for cooling the water sufficiently, such as cooling towers and ponds. This subject, however, will be treated more fully under this specific heading.

CHAPTER III.

EXCAVATION AND FOUNDATION.

Selection of Site. — Obviously one of the first things to be considered in the selection of a suitable site is the character of the foundations required, and where accurate and reliable information cannot be obtained in other ways, some preliminary exploration is advisable, before the purchase of the property is concluded. In order to secure economy, and at the same time avoid all danger of insufficient foundations, it is a good plan to test the bearing value of the soil. This can be conveniently done by sinking test pits within the area of the proposed excavation, and applying a test load, or the test load can be omitted when soil of a well-known character is found.

Test Holes. — In alluvial soil or made land a thorough exploration should be made by borings carried deep enough to give an accurate knowledge of the underlying strata. When rock is met with it should be pierced to a sufficient depth to make certain that it is not an isolated boulder. The holes should be put down from twenty-five to fifty feet apart and should be located so that an intelligible plot can be made. When the magnitude of the project does not warrant the use of well or core drilling machines, test holes can be put down by driving iron pipe; a small pipe and a large one can be used, the large one being used as a casing to prevent the hole caving in and the smaller pipe being driven inside of it. A core can be secured by leaving the lower end of the smaller pipe open and working without water, but an easier method is to force a stream of water down the smaller pipe, which returning to the surface by the larger pipe brings up specimens of the soil. With a device of this kind holes can be put down fifty feet more or less, dependent upon the character of the ground.

Character of Soil. — When rock is met within a moderate depth, the foundations should be carried down to it, the surface of the rock under the piers and walls should be leveled off to give a good bearing, all loose and rotten stone being cleaned off until a solid material is reached. The bearing value of rock varies within wide limits, according to its quality, from 20 to 200 tons per square foot, the allowable value being one-tenth of its crushing strength.

A clean sand makes an ideal foundation, having a good bearing value and being easy to excavate, in addition it can be utilized in the mortar and concrete, with considerable saving in expense. Gravel, except of the cemented kind, possesses similar

advantages. Quicksand, either wet or dry, when in thin layers should be entirely removed; where the bed is underlaid by a firm strata, and removal is impracticable, it can be confined by means of a concrete cofferdam, and the foundation can then be floated on it, the footing or mat covering the entire area within the dam.

In soft alluvial soil or made land, piling is necessary for heavy foundations. Piling is used in two ways: piles are driven to rock or to a solid stratum below, in which case they act as columns supporting the foundation; or they are driven down in soft soil to compact it, in which case their bearing power is dependent entirely on the friction between the piles and the soil. Wooden piles must be cut off below the level of the permanent ground water line in order to preserve them from decay; in some localities there is considerable difficulty in locating the ground water line, which is liable to sink or rise several feet according to whether the season is wet or dry. In early practice a wooden platform was laid, built up of caps, drift bolted to the tops of the piles, on which the heavy flooring of squared timbers was laid; this was necessary in the days when foundations were built up of dimension stone and brick. The modern practice is to use a mat of concrete, in which the tops of the piles are encased six inches to a foot; when the character of the soil is such that it is difficult to deposit concrete directly on it, it is customary to excavate between the piles to a depth of two to four feet and fill in with sand or gravel in thin layers well rammed.

As a general rule the firmness of the soil increases with depth, but there are exceptions; in Chicago there is a firm upper layer of soil from ten to twenty feet in thickness underlaid by a soft clay stratum about seventy feet in thickness, beneath which is a thick stratum of very firm clay; this same condition prevails in many localities near lakes or rivers, and also in Holland. The early practice in building foundations on such soil was to float them on a sort of a raft or mat covering the entire area; in some cases piles were driven before this mat was put in. In building foundations for some plants a number of isolated piers have been used for supporting the buildings and machinery, the principal disadvantage of such construction being the impossibility of insuring equal settlement of all the different piers.

Clay varies greatly in consistency, ranging from very nearly a fluid to a hard shale; this latter on exposure absorbing water from the atmosphere and disintegrating. Clay varies greatly according to the opportunity it has of absorbing or losing water, and this property makes it troublesome. It is desirable to arrange so that it will be thoroughly drained, but this may cause trouble with surrounding structures, numerous instances of which have occurred in Chicago. Sand or stone can be spread on clay over the area to be covered by the foundation, being well rammed down; the stones used for this purpose should be small enough to permit their being handled by one man.

Concrete Mat Construction. — Since power houses are usually built on the water front, it frequently happens that alluvial soil or made ground is met with, in which cases piling must be used unless a firm underlying stratum is found sufficiently close to the surface to justify the carrying of the foundations down to it. In soil of this character it is sometimes attempted to economize by the use of piles and isolated

piers, but the result is not satisfactory. In such places the purpose of the foundation is not to prevent settlement, but to insure that such settlement as occurs will be equal over the entire area; this can be best insured by driving piles over the entire area and placing a heavy mat of concrete over them, tying the heads of the piles together firmly. The mass of this mat and the foundations should be sufficient to take up all the vibration due to the machinery, which is rarely in thorough running balance. In a case in Holland the entire structure developed a tendency to slide bodily in one direction, owing to the unbalanced moment of the engines, which happened to be in synchronism with each other. The trouble was cured by running some of the machines in the opposite direction, which caused their moments to oppose each other.

A prominent example of the mat construction for foundations is the Long Island City power plant of the Pennsylvania, New York and Long Island Railroad Co., which has an ultimate capacity of fourteen 5,500 K.W. and two 2,500 K.W. Westinghouse-Parsons turbo-generators. The plant is located on a plot of ground 200 × 500 feet, a length of 265 feet being at present all that is occupied. Wooden piles 25 to 30 feet in length were driven over the entire area, as seen in accompanying illustration Fig. 1, their center distances varying from two feet to three feet four inches, being closest together under the stacks and at other points where heavy concentrated loads occurred. About 9,500 piles were driven, and they were cut off at a uniform height. Over the piles a monolithic mat of concrete is placed, in the lower side of which the heads of the piles are embedded. This mat is six feet thick and the concrete used is a 1 : 2½ : 5 mixture of Portland cement, sand and broken stone. This concrete was placed in winter, and to avoid all trouble from freezing the precaution was taken thoroughly to drain it by means of cross and longitudinal drains, of 10 and 12 inch vitrified tile pipe. The entire structure rests on this mat. Cross grillages of 12-inch I beams are used to distribute the column loads, the beams being embedded in concrete; the columns are bolted to the upper layer of the grillage.

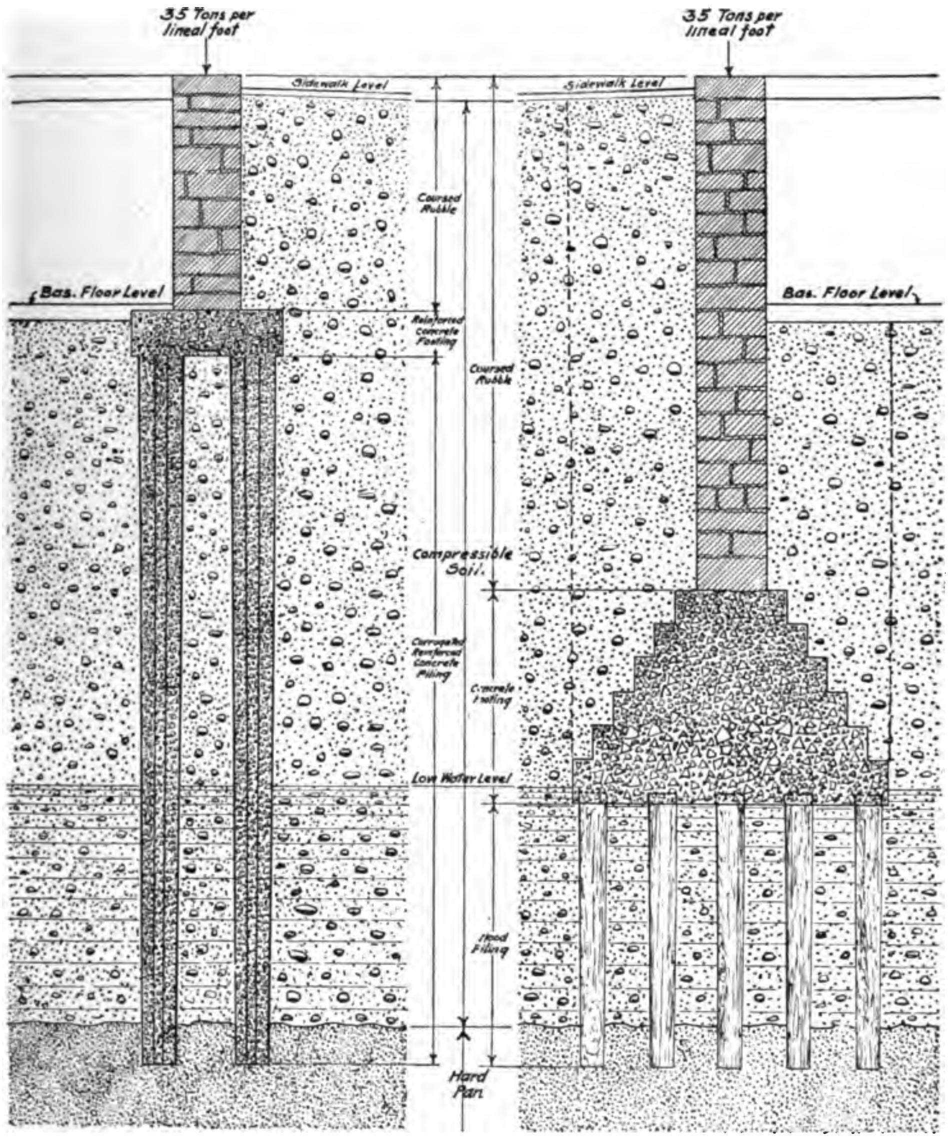
Concrete Piles. — The use of concrete for various purposes is increasing, and in addition to its use for foundations of a massive character it is also employed for walls, floors and piles, being used both plain and reinforced with steel. Two methods are employed for concrete piles; in one the piles are molded and then driven, in the other a mold is driven with a removable core and the concrete placed after the removal of the core. The concrete pile is comparatively new, and several different forms are widely advertised; for many reasons they are preferable to timber piles; they cannot decay, and for this reason they can be brought up as high as desired and more economical foundations secured owing to the fact that the ground water line does not, with concrete piles, signify the point where the footing for the piers must be laid. This may mean a great saving in the line of excavation and foundations. As the bearing power of concrete is much higher than that of wood, heavier loads can be placed on a pile, while at the same time there is no limit on the size or diameter at the butt as is the case with wood; wood piles rarely run over 12 to 14 inches at the butt;

for ordinary work, since large timbers are very expensive, concrete piles, as large as desired, within limits, can be used. For this reason fewer concrete piles will be required for the support of a given load, and they are in effect downward projections of the monolithic mass of the foundations.

FIG. 1. Piles cut off ready for Concrete Cap, Long Island City Plant.

Test of Piles. — The difference in bearing power between a conical and a cylindrical pile was shown by an experiment tried on some work at the United States Naval Academy at Annapolis, Md. A Raymond pile core, tapering from six inches at the point to twenty inches at the butt, was driven 19 feet, until the penetration under two blows from a 2,100-pound hammer falling twenty feet was seven-eighths of an inch. A wooden pile $9\frac{1}{2}$ inches at the point and 11 inches at the butt, and of the same length, 19 feet, as the conical pile, had a penetration of $5\frac{5}{16}$ inches under two blows of the same hammer falling 20 feet. A $17\frac{1}{2}$-foot test pile having the same dimensions as the concrete pile above mentioned, and having a penetration of 1 inch under twenty blows of a steam hammer, was loaded with 41 tons. Levels were taken during the loading and at intervals for one month. At the end of the month the total settlement was 0.007 foot or $\frac{3}{32}$ inch.

Bearing Power of Soil. — The size of the foundation necessary for supporting the load to be carried is of the first consideration. In the matter of the machinery care should be taken to include the entire weight, including the water in heaters, con-



Corrugated Reinforced Concrete Piling *Wood Piling*

FIG. 2. Comparison between Foundation employing Wooden Piling and Foundation with Concrete Piles.

densers, etc. For the safe bearing power of soils the values in the following table as given in Baker's Treatise on Masonry Construction are submitted:

TABLE III — SAFE BEARING POWER OF SOILS.

Kind of Material.	Safe Bearing Power in Tons per Sq. Foot.	
	Min.	Max.
Rock — the hardest — in thick layers, in native bed	200	—
Rock, equal to best ashlar masonry	25	30
Rock, equal to best brick masonry	15	20
Rock, equal to poor brick masonry	5	10
Clay, in thick beds, always dry	4	6
Clay, in thick beds, moderately dry	2	4
Gravel and coarse sand, well cemented	8	10
Sand, compact and well cemented	4	6
Sand, clean, dry	2	4
Quicksand, alluvial soils, etc.	0.5	1

Weight of Masonry. — For the total bearing stress of a foundation on the soil the weight of the foundation itself must be included. For use in this connection, Table IV, taken from the same authority, gives the weights of various types of masonry:

TABLE IV — WEIGHT OF MASONRY.

Kind of Masonry.	Weight in Lbs. per Cu. Ft.
Brickwork, pressed brick, thin joints	145
Brickwork, ordinary quality	125
Brickwork, soft brick, thick joints	100
Concrete, 1 cement, 3 sand, and 6 broken stone	140
Granite, 6 per cent more than the corresponding limestone	—
Limestone, ashlar, largest blocks and thinnest joints	160
Limestone, ashlar, 12" to 20" courses and 3/8" to 1/4" joints	155
Limestone, squared stone	148
Limestone, rubble, best	142
Limestone, rubble, rough	136
Mortar, 1 Rosendale cement and 2 sand	116
Mortar, common lime, dried	100
Sandstone, 14 per cent less than the corresponding limestone	—

Size of Foundation. — The sizes of foundations are ordinarily given by manufacturers, either in catalogues or blue prints, which are easily procured. In many instances, however, the low bearing power of soils necessitates the use of foundations larger than those so given. In such cases sizes must be figured for the bearing power of the soil in question, samples of which have been previously obtained on the ground. In cases where detailed drawings of foundations are not furnished by manufacturers, care should be exercised to have the foundations for reciprocating machines of ample mass to take care of shocks and vibrations due to the motion of the parts of the machine.

Location of Foundation. — In locating a foundation every precaution should be taken to see that the center lines are properly established, and that the dimensions are properly laid out, inasmuch as a foundation once in place is very hard to remove. This may also be said in regard to the location of the anchor bolts. Substantial templets should be constructed so that the anchor bolts will remain in their proper position while the concrete is being filled in around them. Anchor bolts may be either embedded directly in the concrete, or where very long anchor bolts are used iron pipes may be placed around them, in order to allow space for adjusting the bolts to the machine bed-plates. Where pipes are not used, wooden boxes may take their place. These wooden forms are generally removed at the completion of the foundation, but the pipes remain. In cases where permanent pipes are embedded in the concrete and anchor bolts are to be inserted at the time of the erection of the engine, such pipes should be supplied with wooden plugs so that no foreign matter may fall in upon the anchor plates and prevent the possibility of readily entering the bolts.

Concrete Forms. — In the construction of forms for smaller foundations these should be so made that they may be easily taken apart and used again. The thickness of the planking and timbers used for forms will depend on the size and height of the foundation. A foundation 25 feet high, as has been used for large units in some of the New York power plants, requires heavier material than is necessary for foundations for smaller units. Where the exterior finish of the foundation is required to be smooth or exposed to view, the planking material should be surfaced and edged so as to make a smooth, tight-fitting form. In such cases gravel or stone should be well worked back from the form, so as to leave a cement face. The concrete used for bedding foundations is usually 1 : 2½ : 5, or in cases where heavier foundations have been employed the mixture is 1 : 3 : 6. The mixing plant should be located as near the foundation as possible in order to facilitate the handling of material. In prominent power plants a mechanical mixer has been installed. Special sheds have been erected to store the cement, while stone and gravel are stored at the side of the mixers.

Concrete Mixture. — The sand used for concrete should be clean and sharp. The cement should be of the best quality, freshly ground Portland. The broken stone should be thoroughly clear of mud, dust and dirt, and should be not of larger size than will pass through a two-inch ring in any direction. Concrete for foundations should be mixed rather wet and well rammed in place until a film of water stands on the surface. The concrete should be quickly laid in thin layers not to exceed nine inches in thickness, and each layer well rammed before the next succeeding layer is applied. In the construction of the various piers and parts of a foundation each should be carried to completion without interruption after the work is once begun, so as to secure a homogeneous and monolithic mass. The forms should not be removed until the concrete is set. All foundations should be allowed to set at least several days, dependent on the size of the foundation, before any machinery is placed. In dumping concrete the fall should not be more than 8 to 10 feet, for the reason that,

at such heights, the gravel will separate in its fall from the cement, and water-pockets will form around the gravel tending to destroy the bond.

Grouting. — Allowance should be made on top of foundations, varying from one-half to one inch between the foundation and the bottom of the bed-plate, for grouting. After the bed-plates have been adjusted in place and securely anchored, all of the space left between the foundation and bed-plate, and around the anchor bolts, is filled with a rich, thin cement mortar.

Waterproofing. — Usually the building foundation is made of monolithic concrete; where, however, brick is preferred, first-class material only should be used. The brick should be of hard burned clay, the mortar, Portland cement. Wherever the building foundations are located, be they of concrete or brick, and providing the soil be damp, provision should be made to waterproof same.

BUILDING.

Material. — In power plants a prime necessity is a fireproof building, guaranteeing continuity of service. This can best be secured by a structure entirely of brick, steel or concrete. The following materials are available: granite, concrete blocks, terra cotta, reinforced concrete, common brick and corrugated iron. The advantages of any particular method of construction must depend upon the class of labor available. In many countries skilled labor is easily obtainable. In others everything must be brought to the building. In the latter case it is advisable to use materials which can be handled by casual labor, such as corrugated iron siding or reinforced concrete, which can be molded to suit the structure. A skilled foreman, however, is necessary.

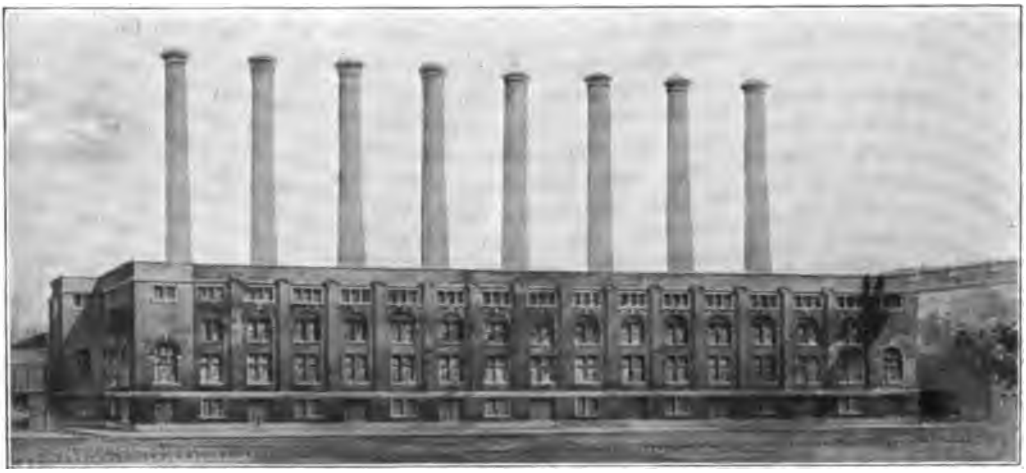


FIG. 1. Delaware Ave. Plant, Philadelphia.

Floors. — In the boiler room a concrete floor is typical of the best construction. In many plants brick pavement has been successfully used in this portion of the building.

In designing concrete floors, both for boiler and generating room, it is desirable to provide drainage slopes with floor drains at suitable points so that wash-water, drips, leakage, etc., will not form puddles. All corners where this floor abuts at the foundations or walls should be rounded and no sharp corners should be permitted anywhere in the plant. This serves a two-fold purpose: re-entrant corners are rounded for sanitary reasons, while projecting corners are rounded to avoid chipping off by accident.

In large plants the flooring is often kept back from around the generators, which extend down into the basement to allow room for the removal of the fields or armature. In American plants sometimes a removable wooden floor is put in for such openings. In Europe, particularly on the Continent, the practice is to run the concrete floor close up to the generator frames, leaving a small amount of clearance to avoid danger of short circuits. This flooring is arranged so that it can be broken out should it be neces-

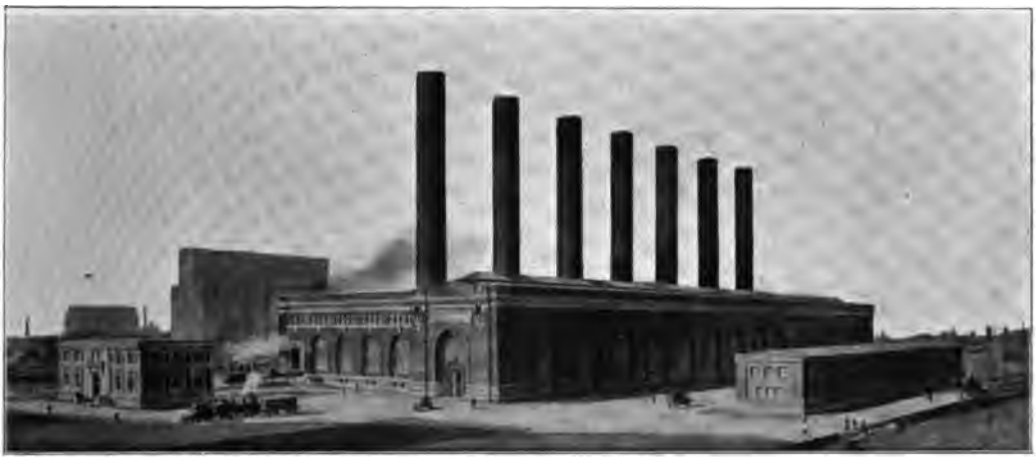


FIG. 2. Fisk Street Plant, Chicago.

sary to remove the entire machine, so very rare an occurrence, however, that it is not necessary to spoil the appearance of the plant to cover such an emergency.

In modern practice reinforced concrete has been frequently employed with great success. These concrete floors, usually of five inches thickness, contain a layer of wire netting or iron rods, and are molded directly on the floor framing without arching. This construction has many advantages, the principal difficulty, however, lies in the fact that holes cannot be broken in the flooring without cutting the reinforcement.

Some authorities claim that brick or cement flooring is undesirable in rooms containing machinery, on account of the grit produced by wear being stirred up by walking or sweeping, and recommend wooden flooring. Wooden flooring should not be used for the reason that around machinery there is more or less dripping of oil which soaks into the floor, and very shortly gets it into a very inflammable condition. In fact, the whole trouble with some power plant fires has been due to an insignificant blaze in the wooden flooring causing thousands of dollars worth of damage to the

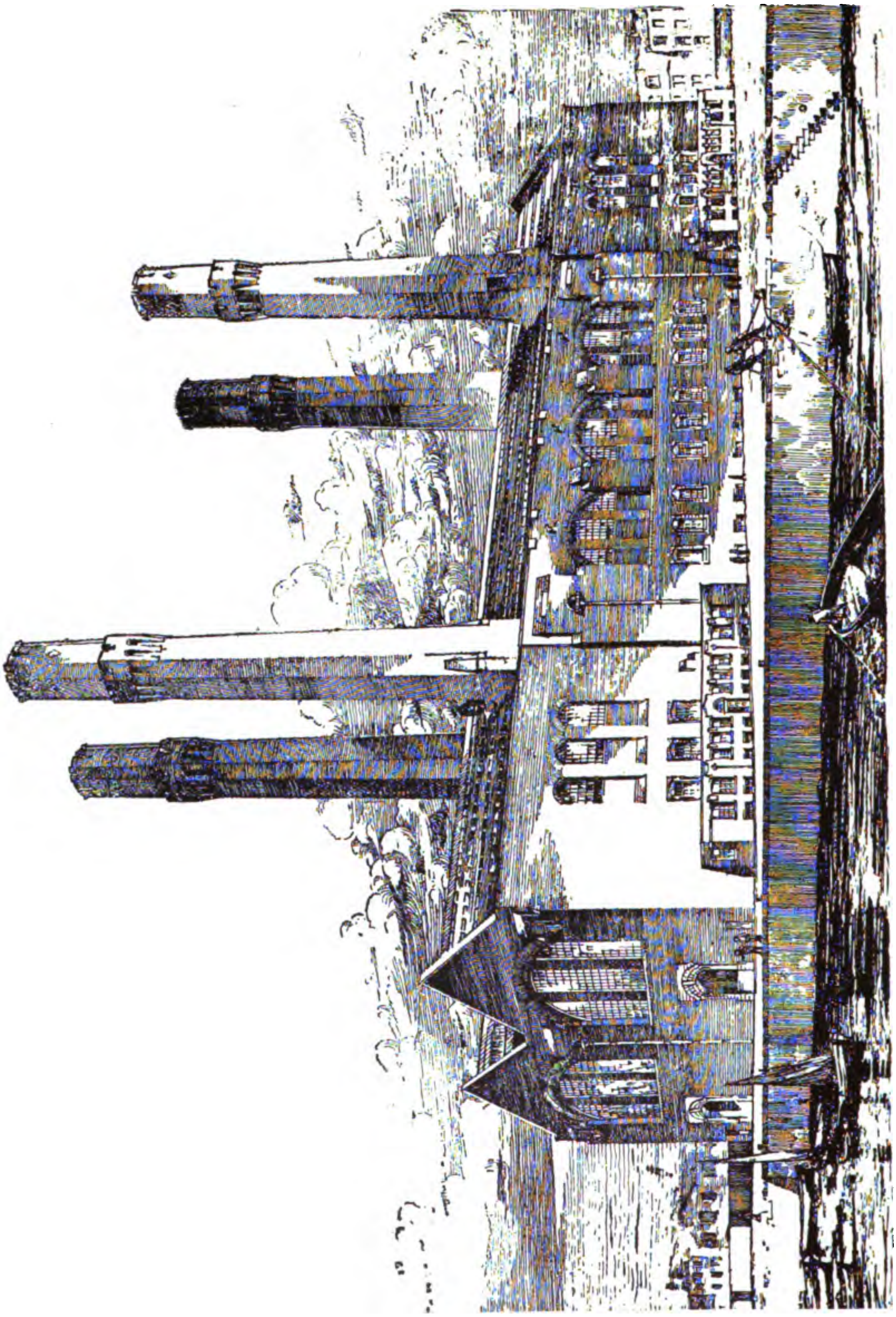


FIG. 3. **Power Plant at Greenwich (England) when complete, but not showing Pier and Coal Handling Plant.**

apparatus. In an electric power station it is almost impossible to use water in case of fire on account of the danger of short circuits, and sand or earth must be spread on the blaze.

The floor arches, whether all brick or concrete, should be so designed that their crown is below the level of the tie rods in the floor system. This question has been treated in the chapter on steel structure.

In many plants bluestone bearers are set in foundations, and in the walls of the building where the floor beams bear. This is an unnecessary refinement, since it is perfectly practicable to use a heavy steel plate for this purpose, which can be grouted in position with much less trouble than is required to set the bluestone accurately. Cast-iron or built-up lintels should also be so proportioned that the use of stone bearing plates is unnecessary, for steel properly grouted is much better.

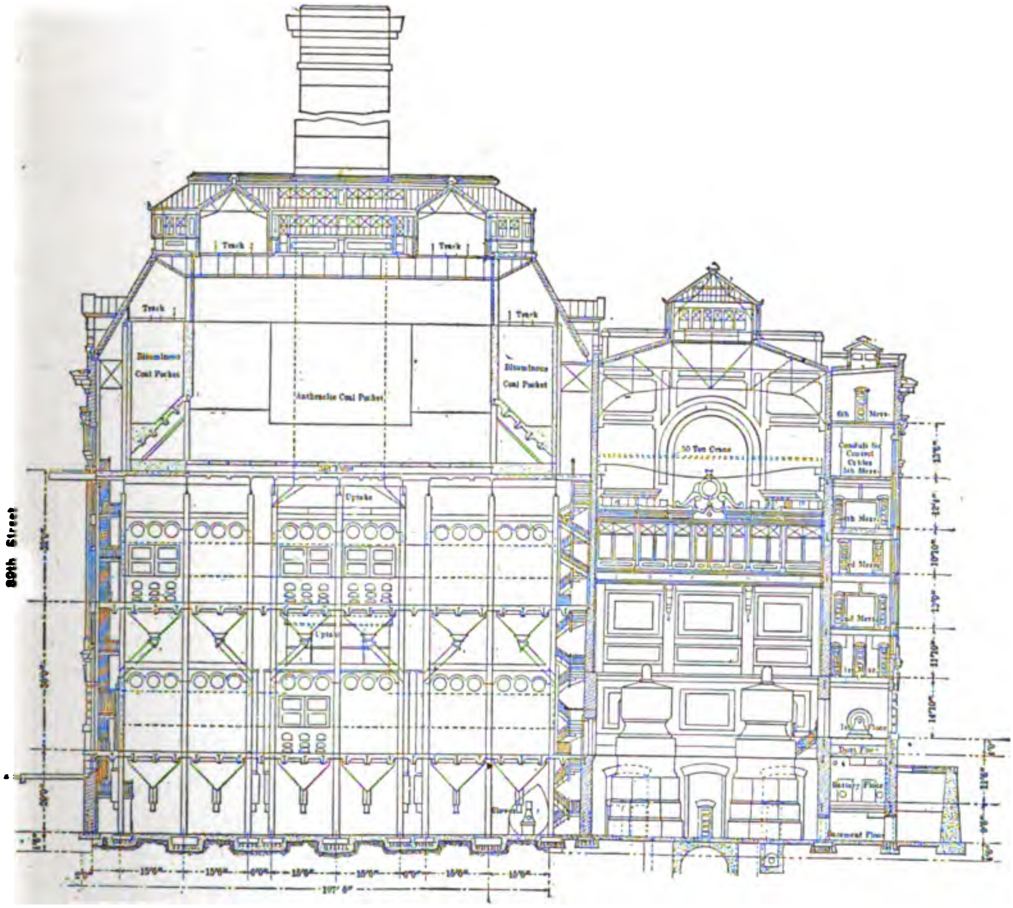


FIG. 4. Structure of Waterside Plant No. 2, New York (*Electrical World*).

Pipe Trenches. — All piping should be run in an inconspicuous manner, preferably in trenches under the floor, with the exception of live steam piping, or if there is a base-

ment in the plant, as is the case with reciprocating engine stations and horizontal turbine plants, the piping, as far as possible, should be kept in the basement. Where it is necessary to bring pipes through the floor, they should be surrounded by cast-iron thimbles, which should extend at least one inch above the floor to prevent wash-water damaging the pipe covering. In some instances, however, as a matter of appearance, these thimbles are made flush with the floor construction. An endeavor should be made to locate all these floor openings before the forms for the floors are built. In case these floors have to be put in before the piping, it is advisable to build in temporary wooden forms somewhat larger than the thimble proposed to be used, so that the thimble can be centered on the piping after it is installed. The thimbles used for this purpose should be of sufficient size to permit the pipe flanges to pass through them with ease.

Switchboard Gallery. — In the switchboard gallery concrete floors must be designed so as to give suitable room for all ducts and passages necessary for the wiring. In some plants part of the flooring is made out of slate or soapstone slabs, which can be removed should the necessity arise. The reason for employing these materials is that these stones contain very few metallic elements and are, in effect, first-class insulators.

Walls. — The engine room should be separated from the boiler room by a fire wall, with as few openings as practicable, and these openings should be closed by fireproof doors. This wall is, in some countries, required by the fire underwriters to project several feet above the roof, and wherever pipe openings are necessary in it cast-iron thimbles should be provided. Doors in it should be so located that direct passage is secured to the firing aisle, and, in the generator room, it is desirable to provide a gallery, three or four feet wide, on a level with the boiler-room floor, provided the main operating room is not at this level. This gallery should be connected with stairways to the main floors, and the machine galleries when practicable.

In some modern plants the high-tension switches are housed in a building entirely separate from the main plant, though the more general practice is to place them in a lean-to adjoining the main building but separated from it by partition walls. When these switches are distributed among several floors, alongside of the main operating room, large windows should be used in order to provide a maximum of light.

Windows. — All the exterior walls of the plant should be pierced by large windows, preferably glazed with ribbed wire glass where exposed to the direct rays of the sun. The other windows can be provided with plain wired glass, although this is not generally done. Ample skylight area should be also provided for the boiler and engine rooms. If proper skylight construction is used it is perfectly practicable entirely to avoid leakage, and this is of the utmost importance for the reason that electrical machinery located below such skylights would be seriously damaged by drip. The engine-room monitor and, in some cases, the boiler-room monitor are glazed throughout, or at least in every

other panel. These sashes should be either of the swinging or sliding variety controlled from the floor beneath.

In many plants wooden window sashes and door frames are used, on account of their low cost, but slightly more expensive construction of wooden frames covered with thin tin or copper is better, while the best construction calls for an entirely metallic sash and frame. In the switchroom the outside windows may be provided with fixed sashes, owing to the danger arising from any foreign material blown into the room. Before this was realized, some prominent plants suffered unexplained shut-downs, due to trouble with switches arising from refuse blown in from the street. If movable sashes are used in such rooms secure locking devices should be provided. The openings into the generator room should be fitted with windows which may be opened for ventilating purposes.

Doors. — The operating and boiler rooms should be provided with main doors of sufficient size to enable a loaded freight car to enter the building when the conditions permit of running in a siding. Where it is impossible to obtain railroad service of this character, or for other reasons, the doorway may be of just sufficient size to admit the largest single piece of machinery at a time. A door 12 feet wide by 16 feet high will admit a railroad car and anything that can be shipped by rail. In some cases Dutch doors are used, of which the upper half can be opened for ventilating purposes, the lower portion remaining closed. Where it is desired to open the whole door at once, folding metallic gratings are provided, a number of designs for which are on the market. The doors are usually built of hard wood with bronze hinges, but while very handsome they are not fireproof. They can be sheathed with copper or some other thin metal, which makes them fireproof for all practical purposes. In some cases corrugated or sheet iron doors are used. Swinging doors are for many reasons inconvenient, and there are a number of designs to economize room, viz., sliding doors, vertical or horizontal sectional folding, swinging and rolling shutter doors.

Ventilation. — Where the basement of the building is below the ground level an area should be excavated around the building for light and ventilation. This area should be not less than 5 feet wide, and protected by hand-rails or covered with iron gratings. All of the windows in the lower portion of the building should preferably be protected by iron guards. In some localities it has been found necessary to cover the windows with heavy wire screens of about one-inch mesh.

The ventilating of the engine room practically takes care of itself, owing to the fact that, in order to house the machinery, and permit the installation of the traveling crane, it must have a certain height, and the side and end windows of the monitor provide a means of exit for the vitiated air at the point where it is most liable to collect. The ventilation of the galleries on which the offices and switches are placed is taken care of by the windows in the side wall and the sashes opening out into the operating room. The engine-room basement is well cared for by the hatches required for handling the heavy parts installed there by the crane, and, where reciprocating

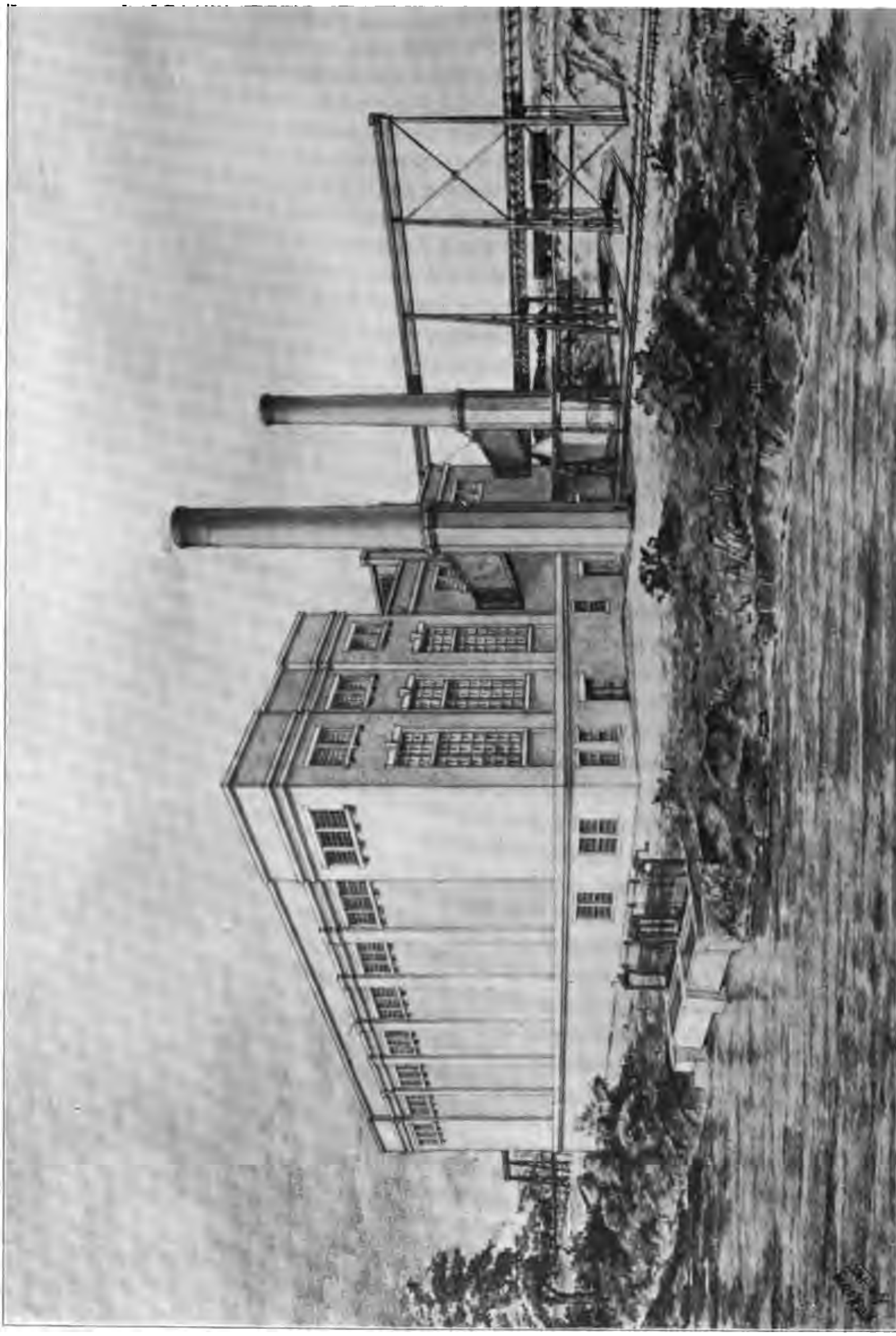


FIG. 5. D. & H. Co. Power Plant (10,000 K.W.) Mechanicville N. Y. 2-3000 K.W. and 2-2000 K.W. Curtis Turbo-Generators; 16-435 H.P. Stirling Boilers; forced draft; Extensive Coal and Ash Handling Systems.

engines are used, the revolving field extending below the floor level acts as a large fan, producing a good circulation of air. For closed rooms for storage batteries, or other purposes, special means must be taken to provide for the inlet and outlet of air, special fans and ducts being put in for this purpose.

The boiler room is often neglected in regard to its ventilation, it being considered that a sufficient change of air is produced by the draft required for the boilers. This, however, is not the case, for such air is taken from the lowest level of the room and leaves all the space above the boilers without any circulation whatever. As this portion of the room receives the radiant heat from the boilers, smoke flues and pipes, it is very uncomfortable for those who work there. The worst troubles in this line are met with

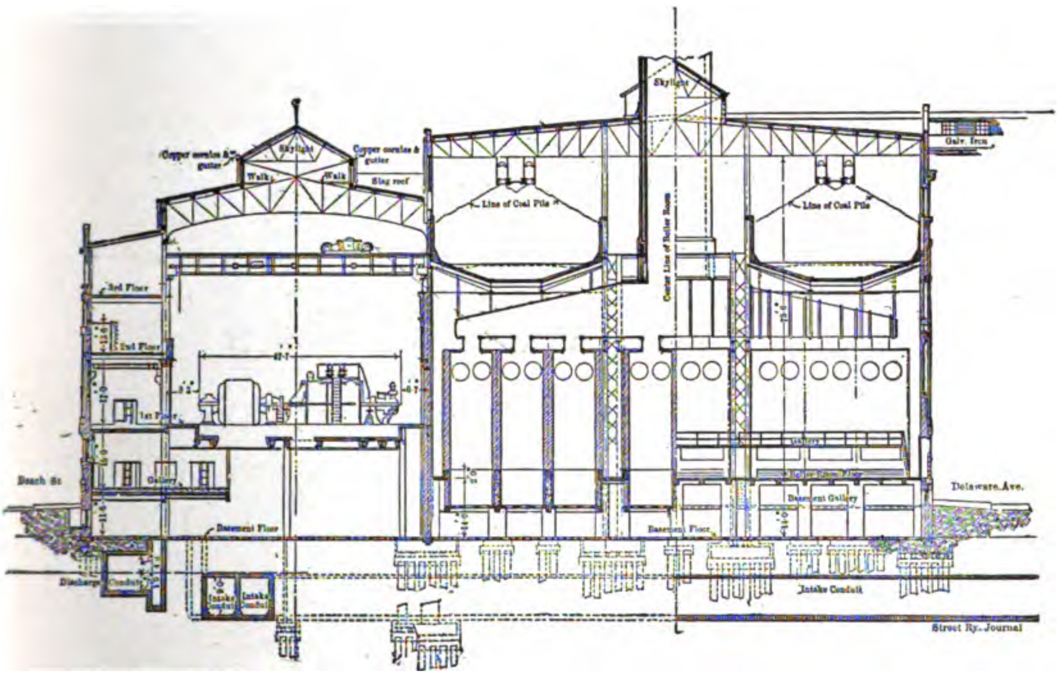


FIG. 6. Structure of the Delaware Ave. Plant, Philadelphia.

in multi-story buildings having overhead coal bunkers, or several decks of boilers. It is desirable that large gratings should be installed at the back of the boilers, so that the warm air can escape upward, and the roof and bunker construction should be so designed that the dead spaces below the sloping sides of the bunkers are well ventilated by louvres or windows. The monitor for the bunkers should be glazed where conveyor machinery is installed, the best practice being to place alternate windows and louvres in this portion of the plant, providing sufficient ventilation and light. Where portions of the boiler room are covered by flat roofs, metal ventilators should be put in to permit the free circulation of air. In some plants buildings have been designed without monitors, and under such circumstances ornamental ventilating towers are

provided at suitable points. This latter practice, however, is typical of continental Europe.

Stairways and Elevators.—Ample stairway provision should be made at all points, since easy access to all portions of the plant is essential. These stairways should be designed of ample width (at least 3 to 4 feet) and with easy steps and straight risers broken by landings, for the reason that many times it is necessary to carry long pipes and other apparatus up and down such passageways. In many plants the mistake has been made of using winding stairs, making it necessary to rig a block and tackle, or use the traveling crane to elevate material into the galleries. Stairs should be built with steel framing, the treads and risers being either cast iron, checkered steel or slate. In some cases the treads are covered with rubber strips or anti-slip material. All the important stairways should have closed risers, while the small stairways leading to light galleries and windows may simply be steps without risers.

In some large modern plants where the operating offices are located on the upper floors, passenger elevators are installed, but it is more usual to provide only a freight elevator, generally located in the boiler rooms of double decked plants.

Toilets and Plumbing. — Another neglected portion of the equipment is that of toilets, baths and lockers. The lockers should be conveniently situated near the

FIG. 7. L Street Plant, Boston.

portions of the building in which the different working forces are employed, and the toilets and baths should be located close to the lockers, enabling the men to change their clothes, clean up conveniently, etc. The lockers should be large enough to con-

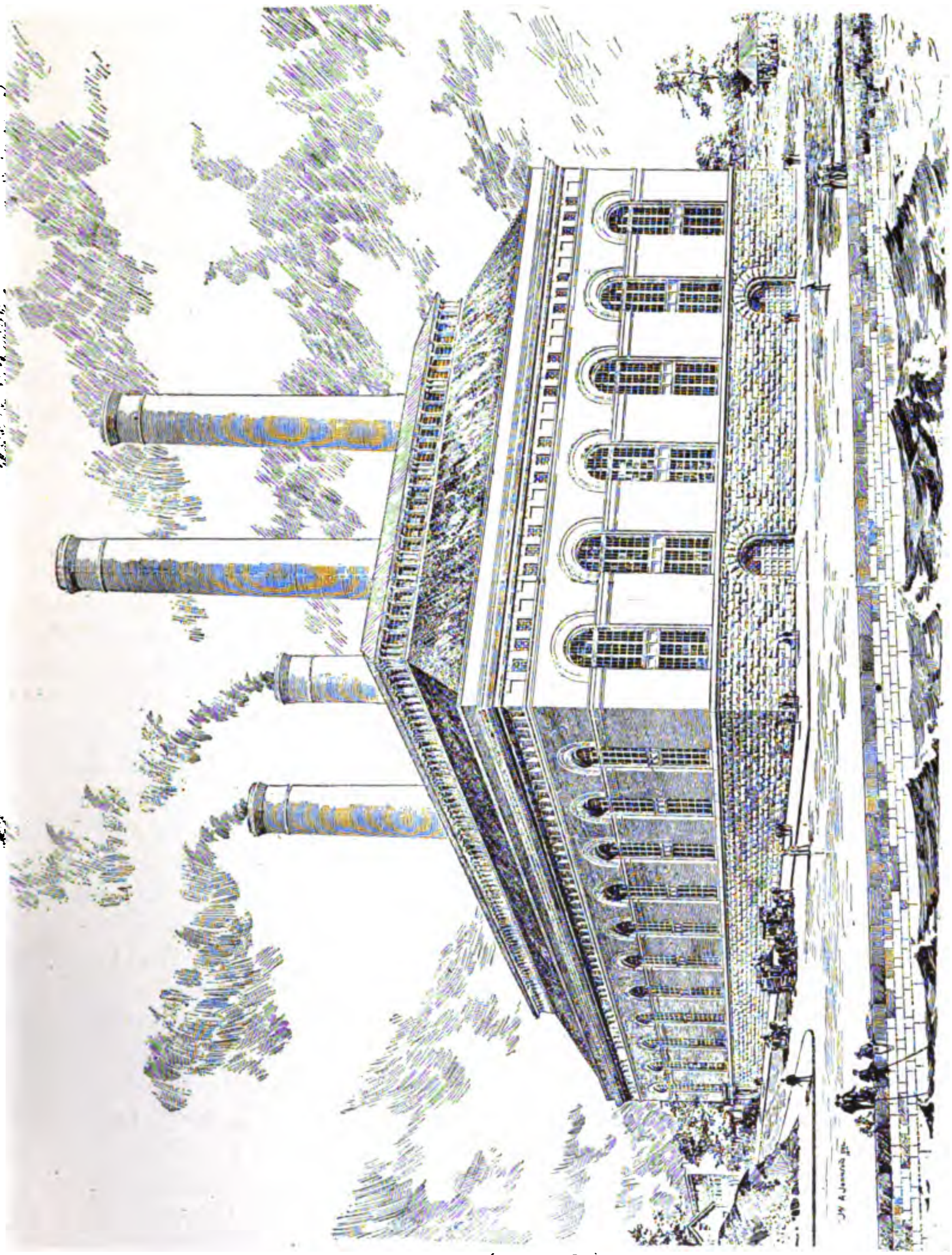


FIG. 8. 74th St. Plant, New York (*Street Railway Journal*).

tain a complete change of clothing, permitting the men in winter to hang up overcoats, while sufficient room should be allowed in the aisles to allow the men to make the necessary changes.

The plumbing should be of good substantial quality, preferably exposed work, enameled iron basins, bowls or sinks. Bowls for this purpose are more preferable than sinks, on account of the considerable saving of wash-water, which is an important factor in the operation of large plants. The toilet-room floors should be tiled and the partitions of white enamel slate or (if more expensive construction is desired) marble. The advantage of white finish is that it enforces cleanliness by making dirt conspicuous. The drains should be run to avoid all ducts and wiring and preferably should discharge into some sewage system, never into the circulating water discharge, although this is sometimes done.

Heating and Lighting. — In temperate latitudes it is necessary to provide for the heating of the building in winter by the installation of radiators or coils at suitable points, or hot-air supply forced to the various portions of the building through ducts.

The house wiring for light should be run entirely in iron armored conduit; in cases where practicable, in the wall or concrete floor. In the walls, chases should be provided for all risers necessary for the house service, exposed pipes being very unsightly.

Roof. — The cheapest roof construction is boards covered with roofing felt, on which is laid a pitch and gravel roof. It is important that no leakage should take place, especially in the generating room, and there are several different specifications for slag and gravel roofing. This roof is suitable for slopes ranging from two inches per foot up to 45°, but is preferably applied to the flatter slopes, for steep inclines increase materially the expense of applying it. The principle of such a roof built of boards is that although it is not fireproof, it has considerable fire-resisting properties if properly constructed. This slag and gravel roof is also often applied to reinforced concrete slabs or arches. In continental Europe, pumice stone is occasionally used in concrete for roof purposes. In America cinder concrete is often used instead of gravel. Both of these concretes are much lighter than the ordinary gravel concrete.

In constructing a gravel roof the concrete is first covered with a layer of hot pitch, over which is laid the tarred roofing felt, the sheets lapping over each other about half the width of the roll, and each sheet being mopped with pitch as it is laid. Over this tarred felt another layer of pitch is applied, on which roofing felt is again spread, usually a triple layer, each sheet being coated with pitch as laid. Over the entire surface an even layer of pitch is then spread, in which, while still hot, slag or gravel is embedded. For architectural reasons it is sometimes desirable to use different roof construction, and the following methods, while they greatly enhance the appearance of the building, add considerably to its expense of construction. Upon concrete slabs standing seam copper roofing is applied. This makes a very handsome finish and never requires to be painted, the copper after a short while oxidizing to an artistic color. Another well-designed roof requires a preliminary preparation in regard to the steel

work, in the shape of "T" irons laid over the roof purlins. Between these book tiles are laid, covered by Spanish roll tile, of a uniform dark color. The advantage of the concrete roof construction, and the two latter methods mentioned, is that they are entirely fireproof. Steep inclines are necessary for any tile or metallic roof, and the height should be, at least, one-third of the span. All roofs should be provided with gutters on the eaves and leaders connecting with the drains. Where flat roofs are used, surrounded by parapet walls, metal flashing should be provided.

For tropical countries the pitch and gravel roofs, so frequently used in the temperate zones, are not suitable, a special material being prepared for use in such climates. In the earthquake zone corrugated iron buildings are erected, the sheets lapping over each other five inches and from one and a half to two inches on the side. These sheets are turned down over the end of the building to give a cornice effect, and the peak of the roof is held by a prepared ridge roll which is supplied with it. In some cases painted corrugated sheets are used, owing to their cheapness of cost. The material should preferably be galvanized, in which condition it should not receive a coat of paint until it is exposed to the weather one or two years, and the surface has become slightly oxidized. One of the troubles with corrugated iron roofing arises from its making an oven out of the building which it covers, unless an air space is provided to insulate the room directly below the roof from the heat, which may be done by applying sheathing on the bottom chords of the roof trusses. This sheathing reduces the height of the room and increases somewhat the difficulty of ventilating it properly. Another trouble with corrugated iron roofs arises from the condensation of moisture upon their surface when the roof, from any reason, becomes cooler than the air. This moisture occasionally dripping into the room below may cause trouble with electrical machinery.

Leaders. — One square inch of leader area is usually provided for each 100 to 150 square feet of roof. The leaders should never be smaller than four inches in diameter. In ordinary buildings galvanized iron leaders are used, while in more pretentious plants, copper of rectangular shape is sometimes employed. All leaders should be provided on their upper ends with removable guards or strainers.

STRUCTURAL STEEL.

Roof Construction. — In modern power plants the tendency towards fireproof construction at all points displaces the wooden roof truss, once so common, by those of steel. The outline of the truss depends upon the kind of a roof to be supported and the slope adopted, the slope depending usually upon architectural considerations, while the material used for the roof is governed in part by the slope. When slate or shingles were the only roofing materials available, steep slopes were necessary in order to shed water rapidly and prevent it working up under the roofing and causing leaks, while with modern methods of waterproofing a slope of two inches per foot is sufficient to supply the requisite drainage. Such roofs are advantageous in many ways, require less material than the steeper pitches, are easier to build, and present

no difficulties in the application of the waterproof covering. Steeper roofs are, however, often used, owing to the fact that they are considered more economical in steel, but this advantage is more than balanced by the additional cost of applying the roofing. In practice the pitch of the roof is governed by the architectural effect and by the skylight construction.

In small plants roof trusses are often supported by the walls of the building, which are stiffened by pilasters at the points where the trusses are set, anchor bolts being used

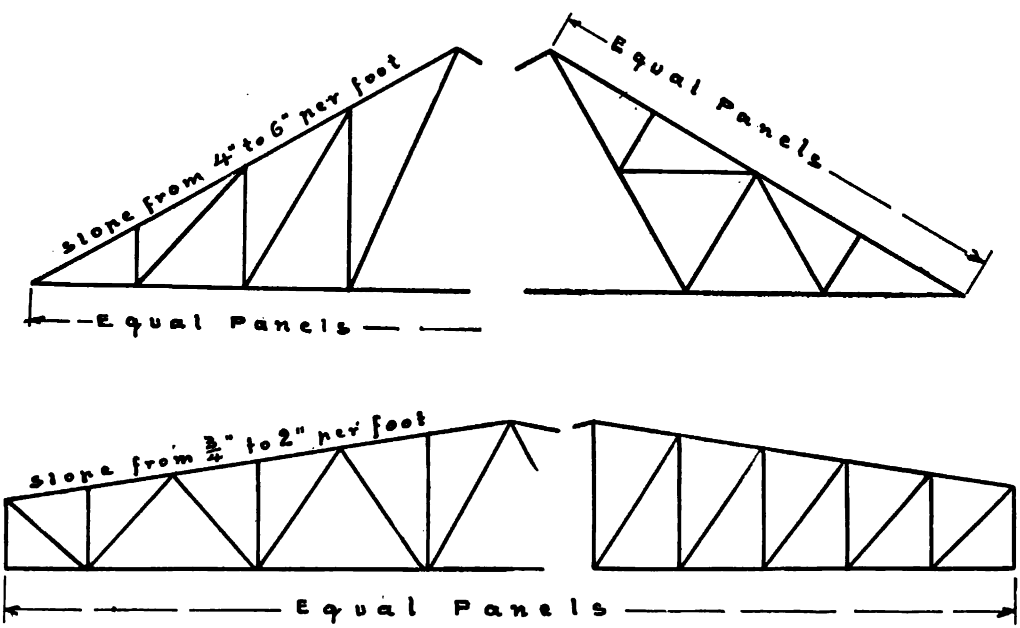


FIG. 1.

to prevent longitudinal or lateral slipping. The top chords of the trusses are tied together by the purlins, which support the roof, and in deep trusses the lower chords are often connected by longitudinal bracing at some of the panel points. In addition, at the end panels, and in long buildings at intermediate panels, angles or rods are used for diagonal bracing in the plane of the upper and lower chords.

The accompanying sketch, Fig. 1, illustrates some of the more usual forms of roof trusses, and the various cross-sections of power plants shown in this volume will suffice to illustrate other forms of trusses in actual use. In designing a roof truss it is necessary to know the distance between the trusses, the span and the load. In power plant work the location of columns is largely determined by the equipment, and it is desirable, for the sake of rigidity, to have the trusses connect directly with the columns. It will be seen that the span and the distance between the trusses are fixed, and that these distances may or may not be such as will permit the best economy of steel work. The loading depends upon the locality of the plant and the roof to be used. In New York City the live load for a roof having a pitch of less than 20° is

50 pounds per square foot, and for pitches exceeding 20° is 30 pounds per square foot. This live load is the vertical component, on the projected area of the roof, of the snow and wind loads. In localities subject to severe wind storms it is necessary so to secure the roof to the building that it will not be lifted by storms. In some cases the roof trusses are made heavy enough to support small bunkers or coal pockets, either continuous throughout the length of the building, or individual pockets suspended in front of each boiler. In addition, the trusses must be of sufficient strength to permit of the steam piping being hung from them, and to carry the coal conveyor. In some plants the breeching or smoke flue from the boilers is suspended from the roof trusses.

Crane Runway. — An overhead crane, operated by power or hand, is a necessity in the engine room. In brick buildings the runway girders are often supported on pilasters on the walls, designed for this purpose. This type of construction, however, is only adapted to comparatively low structures, in locations where masonry is cheaper than steel framing.

Building Material. — In localities where building materials are expensive it is often cheaper to erect a corrugated iron sheathed steel frame structure than it is to put up one of brick or concrete, this being particularly the case in countries where the labor, as well as the building material, has to be imported. A very cheap and temporary structure can be put up with a wooden frame covered with corrugated iron. For these types of buildings, galvanized corrugated iron is used, Nos. 18 to 24 gauge for the roof and Nos. 20 to 26 gauge for the siding (U. S. Standard gauge is used in the United States), and black or painted sheets are occasionally used, but since they are not so durable as the galvanized sheets their use cannot be recommended. The siding is in all cases two gauges lighter than the roofing. The best grade of this material is called "muck bar" corrugated sheeting, and is much more durable where exposed to moist air than the ordinary grades, particularly near salt water. A corrugated iron building can hardly be classed as a permanent structure, and cannot be recommended for power plant purposes owing to the fact that moisture is liable to gather on the lower surface of the roofing and drip on the machinery. This is preventable by cork paint.

There are several methods in use for the design of steel frame buildings, in one the frame is entirely self-supporting and the light curtain walls enclosing the building are supported on the steel work. In another method the walls are self-supporting, and the steel frame, while at the same time self-supporting, is to a certain extent braced by the walls which encase the outer rows of columns and the row between the boiler and engine rooms. In low buildings the walls between the columns are usually light curtain walls of brick or concrete.

Framing. — In large plants located on valuable ground, of which it is essential to utilize the entire area to the best advantage, double and even three deck boiler rooms are sometimes required, above which it is necessary to have sufficient bunker capacity to tide

the plant over short interruptions in the fuel supply, and in some plants the chimneys have been supported on platforms above the firing aisles. In such plants the boilers are supported on the building columns, which in the boiler room are spaced to suit them, and the columns in the engine room are arranged so that the bays there correspond, the columns being placed on the center lines of the batteries of boilers, or on the center

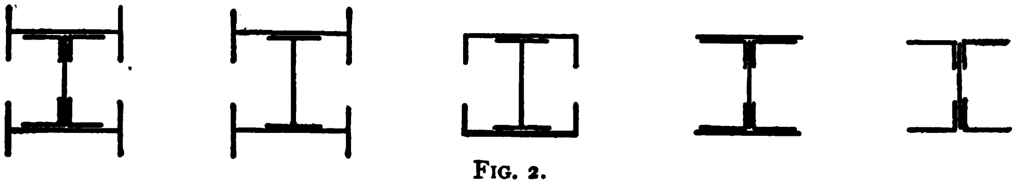


FIG. 2.

line of the space between the batteries. The steel frame of this class of building must be designed to suit the purpose of the building and to permit of economical operation; unobstructed passages and walkways are necessary at a number of points; the floor framing must be designed to permit numerous openings for pipes, coal and ash chutes, conveyors, etc. For this reason it is desirable that all floor beams and girders should be located in vertical planes, even should such an arrangement not conduce to the greatest economy of steel; cross or "X" bracing is not usually permissible, except where it will be encased in permanent walls, portal bracing being preferable. It will usually be found impossible entirely to avoid "X" bracing, and in such cases portal braced panels should be introduced at intervals, in order to provide for passageways. In the boiler-room basement "X" bracing should not be permitted under any circumstances, as this portion of the building is usually reserved for feed-water pumps, heaters and other small auxiliary machinery, together with various lines of pipes, and it is essential that clear and unobstructed passages be left for the safety of the operating force.

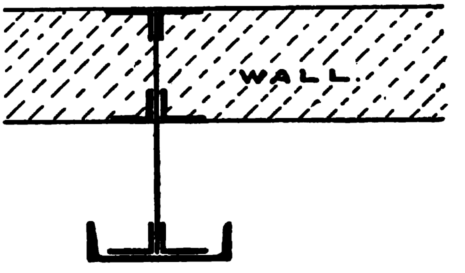


FIG. 3. Crane Column.

Type of Columns. — In regard to the details of design, all of the sections used should be open sections (as indicated in Figs. 2 and 3), accessible at all points, except where encased in brick or concrete, for inspection and painting; that is, box girders or columns should be avoided. In a great many structures, columns built up of channels and plates are used; in fact, this section is a favorite for heavy columns, owing to its low shop cost, but its great disadvantage arises from the fact that the interior of the column cannot be inspected or repainted. In boiler rooms, sections of this character are particularly undesirable, owing to the fact that, in such a location, there is more likelihood of corrosion occurring inside of the columns than outside. In some structures such columns have been filled with concrete after erection, and this practice is preferable to leaving them empty.

Floor Loads. — Brick, terra cotta, concrete or reinforced concrete floor construction is employed in important plants, and the floor system must be designed to support it and the superimposed live load. In many cases it will be found that the floors are subjected to concentrated local loads at various points which require special treatment. In other cases railroad tracks or sidings must be extended into the building, in order to

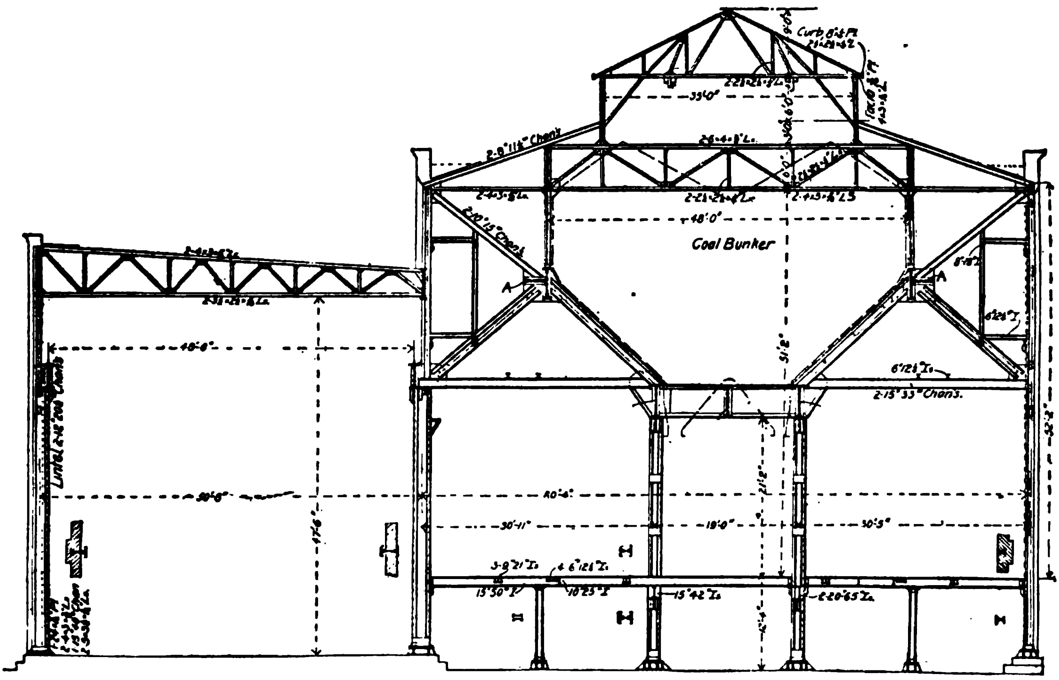


FIG. 4. Steel Structure of the General Electric Co.'s Plant, Schenectady, N.Y.

facilitate the delivery of the heavy machinery in cars, at a point where it can be reached by the traveling crane, while sometimes heavy machinery is carried on the floors, boiler settings, stokers, ash hoppers, etc. The live load for which the floors are designed depends upon the heaviest piece of machinery which will be laid on them or moved over them on skids or rollers. The Interborough power plant on West 59th Street, in New York City, was designed for the following live floor loads, in addition to the dead loads:

	LB. PER SQ. FOOT.
Boiler-room floor	250
Engine-room floor	400
Operating platform around boilers	100
Mezzanine over boilers	150
Upper switchboard floor	300
Lower switchboard floor	400

In addition, local concentrated loads were considered, and in some cases the floors were designed to suit the actual loads imposed on them. In this plant 5,000 K.W.,

11,000 volt generators were installed, driven by twin horizontal-vertical engines. In some other plants floor loads are as high as 600 pounds per square foot, and sometimes even higher loads have been taken into account in designing the floor system. Except during the construction period there is very little likelihood of the actual floor loads ever approaching these figures, but during this period, when material and machinery are being handled and unpacked, large quantities of heavy material are liable to be piled up on any part of the floor, and it may very easily happen that the designed floor loads are exceeded, unless particular care is taken to guard against such occurrences.

Fiber Stresses. — Steel structures are proportioned, in regard to the sections used, by a limit set on the unit fiber stress in tension, which is reduced for compression members, usually by Gordon's formula. In many localities the limiting unit stresses are specified in the building laws, these in some cases being limited in their application to some particular city, while in other cases they apply to a state or nation. As the legal requirements differ greatly in different localities, it is advisable to investigate the subject, unless these are well known. In practice, the fiber or unit stresses used vary from 13,500 to 20,000 pounds per square inch in tension for steel and for most of the important structures the working stresses have been kept between 15,000 and 16,000 pounds per square inch.

Expansion Joints. — In very long buildings the expansion due to changes of temperature must be taken care of during erection, but such precautions are not required in small buildings. The Rapid Transit power house on West 59th Street, New York City, is 693 feet 10 inches long, and is divided in three nearly equal sections by two traverse planes, at which expansion joints are located, the ends of all longitudinal members in one section are riveted, while those in the other sections are bolted through slotted holes which allowed for a temperature variation of two inches. In buildings under three hundred feet in length temperature variations do not cause much trouble and no special precautions are required to care for them. Where expansion joints are used in buildings it is sometimes specified that after the building has been walled in the joints shall be blocked with lead to prevent any motion in the steel work cracking the concrete flooring, etc. The necessity of these joints is only during the erection period when longitudinal expansion is very liable to make it difficult to erect portions of the steel work.

Column Base. — The columns are preferably designed with a base of sufficient area to permit of their being set directly upon the foundation, but cast-iron base plates are often interposed at this point as they can be leveled up before the column is erected. Grillages are undesirable, but cannot be avoided with heavy column loads. The general practice is to rest the columns on the foundations, depending upon the bracing and floors to give the structure stiffness and its weight to hold it down and prevent lateral motion, assisted by the concrete encasing the grillage and base of the

column. In power plants it is desirable to have the structure rigidly secured to the foundation by bolts, the foundation being preferably a mat under the entire structure instead of a number of isolated piers, for such a construction makes a very rigid building.

Floor Beams, etc. — The use of floor arches causes a lateral thrust against all of the beams composing the floor system, and for this reason it is necessary to introduce tie rods suitably spaced to take care of this stress. These tie rods should always be placed high enough so that they will be hidden by the floor arches, as this adds greatly to the appearance of the ceilings. In some plants this detail has been neglected and the result, to say the least, is not sightly. Another small point is the provision of curb angles around all hatches and other openings in the floors, which should project from one to two inches above the finished floor level, their purpose being to prevent wash-water, sweepings, etc., going down to the floor below. The value of these curbs is more apparent in those cases where machinery is located on the lower floors or under the galleries and liable to damage from anything falling into it.

Structural Steel of Recent Plants. — The following comparison of the amount of steel in some recent power plants may be of interest:

Name of Plant.	Tons of Steel.	K.W. Normal.	K.W.	Tons of Steel per Sq. Foot.	Tons of Steel per Cu. Foot.
Chelsea	6,000	57,700	.104	.076	.0007
Interborough	12,300	60,000	.205	.088	.0008
Potomac	800	19,000	.042	.027	.0005
Port Morris	2,800	30,000	.094	.075	.0009

The plants referred to in the above table are the Chelsea plant of the Underground Electric Railway Co., London, England; the West 59th Street power house of the Interborough Rapid Transit Co., New York; the Port Morris power house of the New York Central Railroad Co., New York, and the plant of the Potomac Electric Power Co., Washington, D.C. The Chelsea plant has a double decked boiler room with overhead coal bunkers and horizontal turbines. The Interborough plant has a single decked boiler room, economizer floor over boilers, overhead bunkers, chimneys carried on platforms over the firing aisle, and horizontal-vertical twin engines. The Port Morris plant has a single decked boiler room with overhead bunkers, the stacks being carried as in the Interborough plant, and vertical turbines. In each case the boiler room is parallel with the engine room. The Potomac plant has the boiler room at right angles with the engine room, is designed for vertical turbines, and has a single decked boiler room with overhead bunkers. The chimneys in this and the Chelsea plant extend to the ground.

Workmanship. — The following, in reference to workmanship, is based on the standard practice of some of the leading concerns. All material should be punched one-sixth of an inch larger than the nominal size of the rivets, except that material

five-eighths of an inch thick and over must be drilled or sub-punched and reamed one-eighth of an inch larger in diameter, so as to remove all sheared or burred edges. In some cases sub-punching is insisted upon when more than one cover plate is used on columns or girders, in which case the reaming must be done after the parts are assembled and clamped together.

All work must match so accurately that, after assembling, the rivets can be entered without drifting.

Wherever possible all rivets should be machine driven by direct acting machines, operated by compressed air, steam or hydraulic pressure, which shall be capable of retaining the applied pressure after the upsetting has been completed. Field riveting shall be done, preferably, by long stroke pneumatic riveters. Hand riveting must not be permitted for rivets over seven-eighths of an inch in diameter.

The details shall be designed to avoid riveting in difficult or inaccessible places. No bolts should be used, except by permission; they should be turned to a driving fit and the bolt holes should be drilled and reamed after the parts are assembled and clamped together. In many cases, however, the roof purlins are bolted, all other connections being riveted.

The abutting surfaces of compression members should be truly faced to an even bearing. In some cases this clause is extended to cover the tops of column bed-plates in a specific manner, and in some rare instances it is specified that the abutting ends of tension members shall be faced.

All rivets when heated and ready for driving must be clean. When driven they must completely fill the hole and have round concentric heads of uniform size, thoroughly pinching the connected pieces together.

Inspection. — All facilities for the inspection and testing of material and workmanship should be furnished by the contractor to duly appointed inspectors, but the inspection for the raw materials should be made at the mills or foundries where the steel is rolled or the castings made. The inspectors should be allowed free access to all portions of the plant in which any portion of the material is made.

Painting. — In regard to painting there are a number of differing requirements, raw and boiled linseed oil, iron ore or iron oxide paint, red lead paint, graphite paint, etc., and there are a number of proprietary mixtures on the market of more or less value. The proportion of the materials to be used in preparing the paint and the kind of brushes to be used in applying it are sometimes specified. The proportion of red lead used varies from sixteen to forty pounds per gallon of oil, depending upon the quality; a paint containing twenty-five pounds of red lead per gallon of oil makes a very satisfactory coating for steel, the following formula being a very good mixture:

25 pounds of pure red lead.
1 gallon of pure raw linseed oil.
$\frac{1}{8}$ pint of japan, free from benzine.

Iron ore or oxide paints possess the merit of being cheap, and for this reason are much used, but in practice they are not reliable and should be avoided. Boiled linseed oil makes a good coating for iron or steel without a pigment. The pigment addition acts as a filler for the pores in the oil and retards its drying, and for this reason driers are

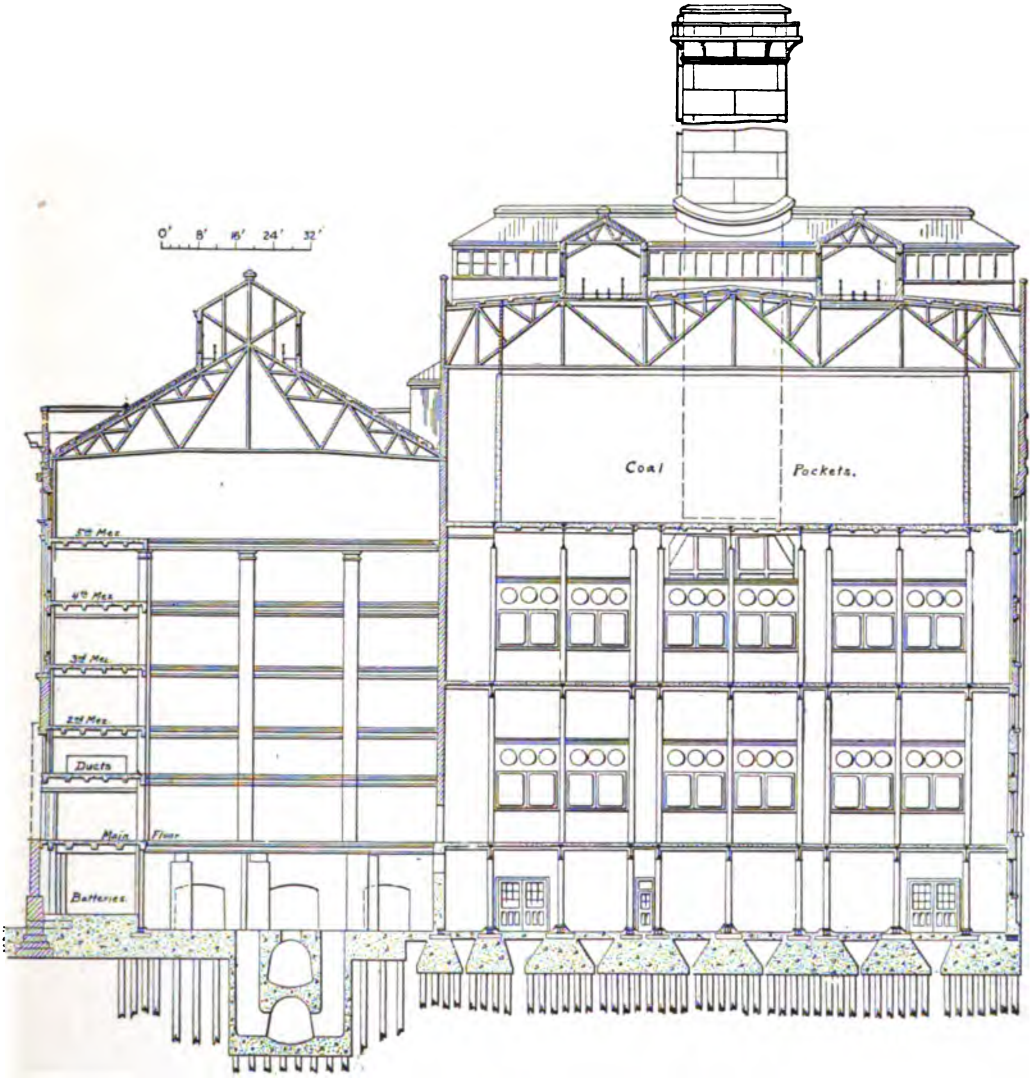


FIG. 5. Structure of the Williamsburg Plant, Brooklyn (*Street Railway Journal*).

used, japan being one of the best materials for this purpose, provided it is free from benzine. The use of benzine, gasolene or naphtha, should not be permitted in any paint which is to be applied to ironwork, for the rapid evaporation of the benzine will cool the material to a point where the surface to be painted will be covered with dew or moisture deposited from the atmosphere.

At least forty-eight hours should elapse between the application of each coat of paint, and painting should not be permitted during freezing or wet weather. In riveted work all surfaces coming in contact should be painted, before assembling, with one coat of paint on each surface. Occasionally it is specified that all portions of the work to be embedded in concrete or brickwork shall receive one or two coats of asphaltum varnish. All the work should receive, at least, one coat of paint before it is shipped, and after erection all places where the paint has been rubbed off as well as the heads of field rivets should be painted, after which the entire structure should receive two coats of paint.

There is very little agreement in regard to the best coating for any particular case, probably because so much depends upon the preparation of the surface to receive the paint, the care with which it is applied and the exposure conditions. All rust and loose scale should be removed before the paint is applied, and the painter should follow immediately after the cleaner.

Insulation of Steel Frame. — At various times it has been proposed to insulate the steel frames of power houses, with the idea of preventing electrolytic action. The complete insulation of the frame is impractical, owing to the fact that a number of pipes must be supported by hangers bolted, or otherwise secured, to the framing, some of these pipes being in connection electrically with the ground water, and an attempt at insulation is extremely liable to localize the electrolytic action at a few points, which would be worse than the troubles arising from the entire omission of insulation.

At the site of erection, or adjacent thereto, it is usually necessary to store portions of the structural material, after it is unloaded and until it is required for erection. This material should be laid on skids, well out of contact with the ground.

Character of Steel. — A large portion of the structural steel made in the United States is made under the "Manufacturers' Standard Specifications" as revised to Feb. 6, 1903, which permits the use of either open-hearth (Siemens-Martin) or Bessemer steel (the Bessemer steel produced in the United States is made by the acid process, no basic Bessemer steel being produced); the practice, however, is growing of specifying open-hearth steel exclusively for most structures, owing to the fact that it is more regular in regard to its physical properties. Bessemer steel, on the contrary, is liable to fail in service, in an irregular and inexplicable manner, and for this reason it is not desirable for structural work.

The following in regard to the quality of the material to be used for structural steel covers the best practice, being made up from the "Manufacturers' Standard Specifications" with modifications based on good authorities.

All steel must be made by the open-hearth process. The phosphorus must not exceed 0.08 per cent. The steel shall be of uniform quality, tough and ductile.

Rivet steel shall have an ultimate tensile strength of from 45,000 to 55,000 pounds per square inch. Structural steel shall have an ultimate tensile strength of from 55,000 to 65,000 pounds per square inch. The elastic limit should not be less

than one-half of the ultimate tensile strength. The percentage of elongation shall be equal to

$$\frac{1,400,000}{\text{Ultimate strength in pounds per square inch}}.$$

Rivet steel, before or after heating to a light yellow heat and quenching in cold water, must stand bending 180° flat on itself without signs of fracture. Structural steel, before or after heating to a light cherry red heat and quenching in cold water, must stand bending 180°, to a curve whose diameter does not exceed the thickness of the sample, without signs of fracture.

The finished bars, plates and shapes must be free from all cracks, flaws, seams, blisters and other defects; must have a smooth surface and be well straightened at the mill before shipment.

The tensile strength, limit of elasticity and ductility should be determined from standard test pieces, cut from the finished material, of at least one-half square inch sectional area, two opposite sides of the test piece shall be the rolled surface, the other two opposite surfaces to be milled or planed parallel; rivet rounds, however, must be tested of the full size, as rolled. All test pieces should show a fracture of a uniform, fine grained, silky appearance, of a bluish gray or "dove" color, and should be entirely free from granular, brilliant and black specks of a fiery luster.

Every finished piece of steel should be clearly stamped with the melt numbers.

The inspection of the steel, to insure its compliance with the specifications, necessarily takes place at the mill, and it is common to introduce a clause in the specifications by which any material accepted at the mill, which, in the process of manufacture, while under the punches or shears, shows that it is not of uniform quality, may be rejected at the shops.

In some cases a drifting test is called for, by which a hole punched in a plate or piece, the thickness of the material in some cases being specified, can be drifted to a larger diameter, without cracking either the edges of the hole or the external edge of the piece, the increase in the diameter of the hole ranging from one-third to one-half the original diameter. The distance from the center of the hole to the edge of the piece may also be specified.

ARCHITECTURAL FEATURES.

Review. — Rapid progress has been made in the general design of central stations by the architect as well as by the engineer. This, of course, varies in different countries, some laying much stress upon the artistic appearance, while others confine attention solely to utilitarian objects, disregarding entirely the general architectural features, as well as the pleasing appearance of the general layout. The conditions in these respects are characteristic of the different countries.

An ornamental building will not increase the operating efficiency of the machinery, while it may increase the fixed charges, but at the same time it is highly desirable,

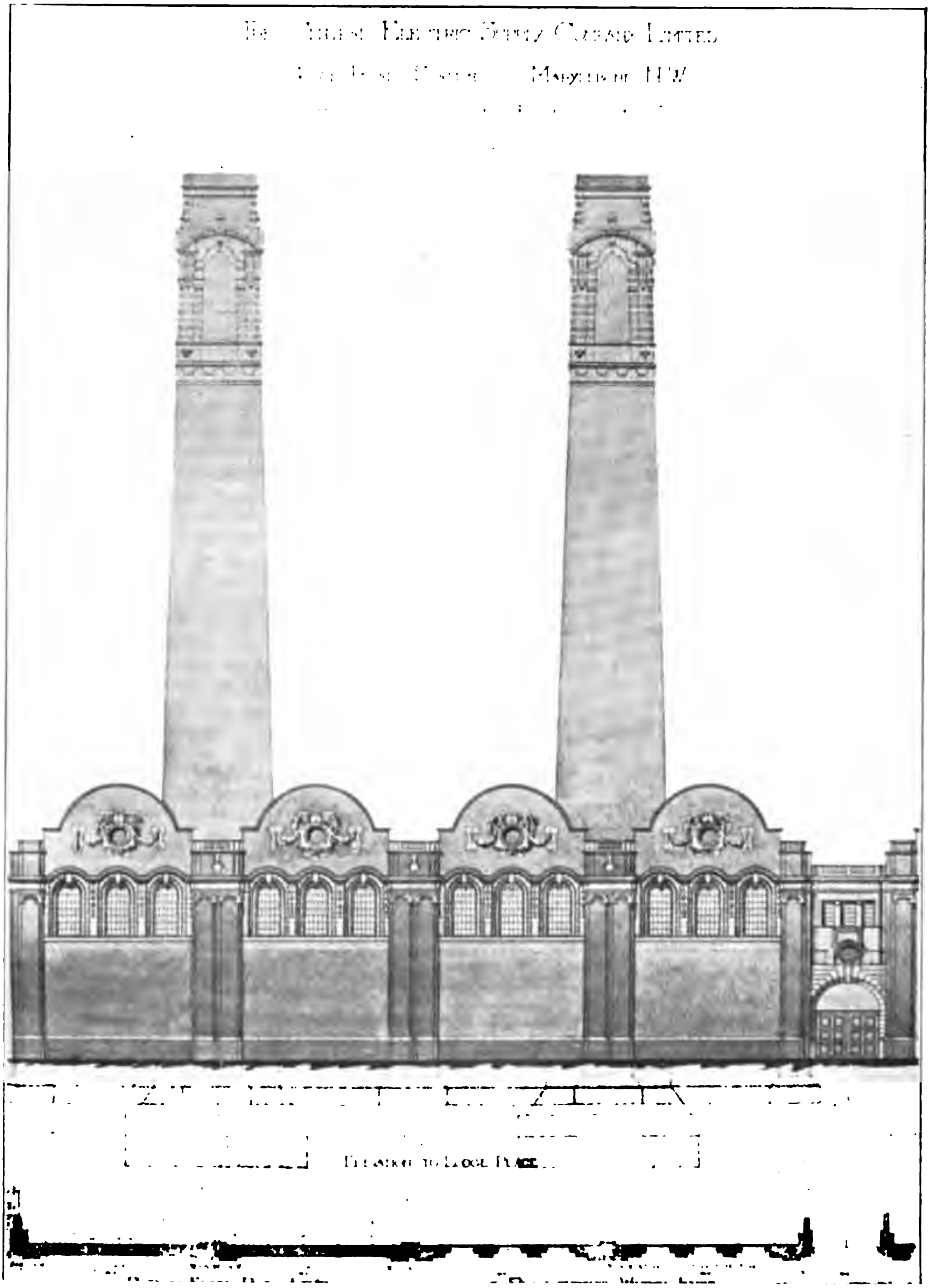


FIG. 1. Façade of the Grove Road Plant, London, showing one-third of the plant. *By Courtesy of Mr. C. Stanley Peach, London.*

from an ethical point of view, that the shell encasing a power plant should be of some appropriate design. To a certain extent it is desirable that the building and its surroundings should present a pleasing appearance, and there is no doubt that such surroundings have a certain effect on the morale of the operating force which conduces to its increased efficiency.

The ultimate and only aim sought for is to deliver power to the transmission lines at the lowest cost, and the building with its contained machinery is but a completed machine for this purpose. The steel frame and the architecture of the building must be adapted to the purpose to be served. There are a number of expensive

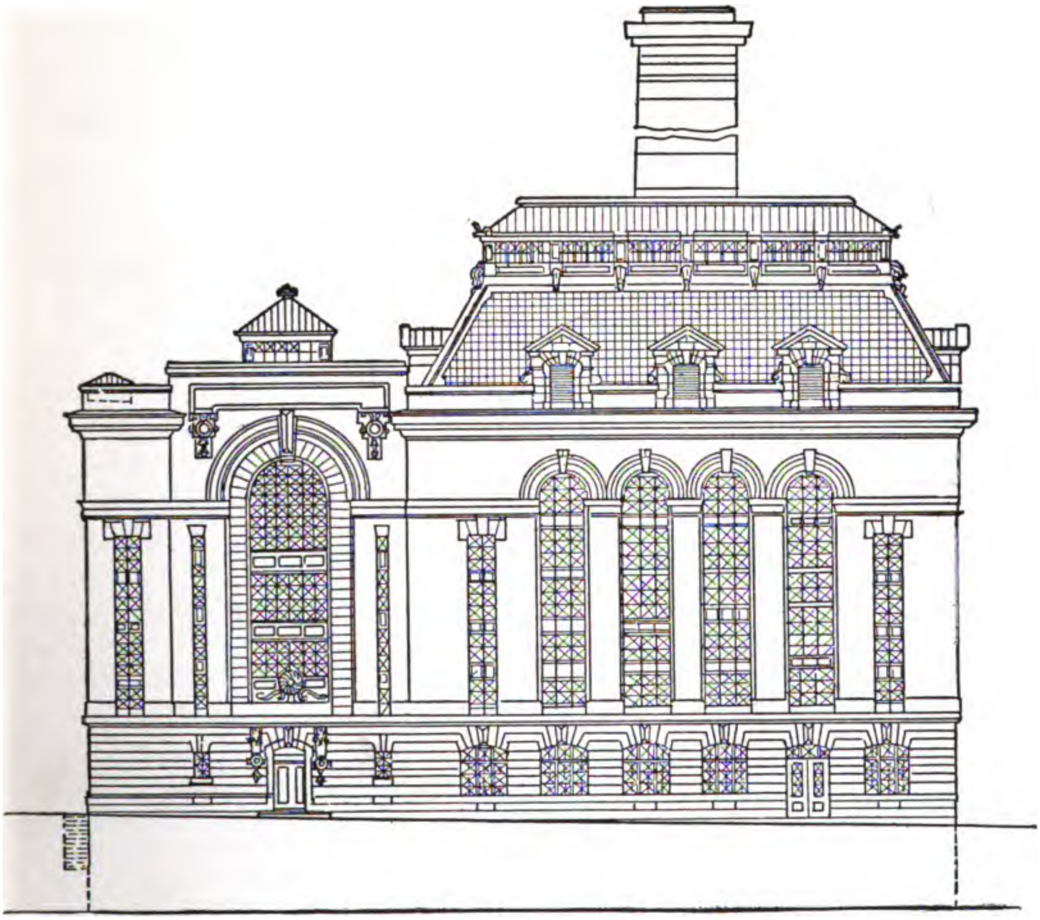


FIG. 2. Façade of Waterside Plant No. 2, New York (*Electrical World*).

power plants, particularly in the United States, which present evidence of lack of co-operation between the engineer and the architect.

In the past few years much more attention has been paid in America and Great Britain to the artistic design of electric generating stations, the architectural appear-

ance of such plants not having had the importance that from the beginning has prevailed in continental Europe.

It is a remarkable fact that the plants in continental Europe which stand out prominently with respect to architectural features and pleasing interior are also the most economical in operation. This close association of art and engineering science is only characteristic of Europe, and if one takes into consideration the great progress there made in the reduction of fuel consumption to produce a horse-power hour (for example, many plants operate with a steam consumption as low as 10 to 9 pounds per horse-power hour) one will realize that engineering design has not been sacrificed to architectural effect. Although the continental engineer may consider that he has artistic taste, he seldom undertakes alone the laying out of the entire plant, but is in close touch with the designers of the architectural staff. Under these conditions it is easily possible to create a structure pleasing to look upon.

In the United States and Great Britain the general practice is to give out the contract for the designing of the plant to a firm of consulting engineers, or where the plant is that of a traction or railroad company an engineering force is engaged and the entire plant is designed in their office, in some cases without the slightest architectural assistance. A few exceptions, however, are noticeable in which engineering and architectural talent have been combined to secure harmonious results. A case in point is the Port Morris plant of the New York Central Railroad, in which the coal tower has been architecturally treated in a manner to harmonize with the main structure, also the New York Subway power house.

One of the prominent European plants is the twin municipal station of the City of Vienna. This plant is located in the suburbs and is surrounded by grass plots in which trees have been set out. The grounds are surrounded by a picket fence. The two main buildings, as well as the auxiliary buildings with their many towers and cornices, are of medieval appearance, typical of the fourteenth century. This style of architecture is much favored on the Continent. The two main buildings are well situated and are symmetrical in every respect, there being two tall, ornamental chimneys for each.

Another architecturally beautiful plant is that of the City of Hanover, Germany. This plant is also located in the suburbs, nevertheless its architectural features are developed to the smallest detail, and the general appearance of the plant is such as not to present a huge building, although the generating room at the left is of great height. This room is provided with wide, prominent arched windows with diamond-shaped panes, thus relieving its appearance of height. A large window area is provided on the side of the generating room, insuring good light. Creditable as the design of the station is, a discord is struck by the old wooden fence that still surrounds the building, and a large and unsightly water-cooling tower at the right could probably have been made to match the building, provided it had been built of steel or reinforced concrete instead of wood. Such inconsistent features, although they detract from the appearance of the plant, are frequently found in otherwise finely designed continental plants, probably due to the fact that the architect was not consulted in connection with these additional features.

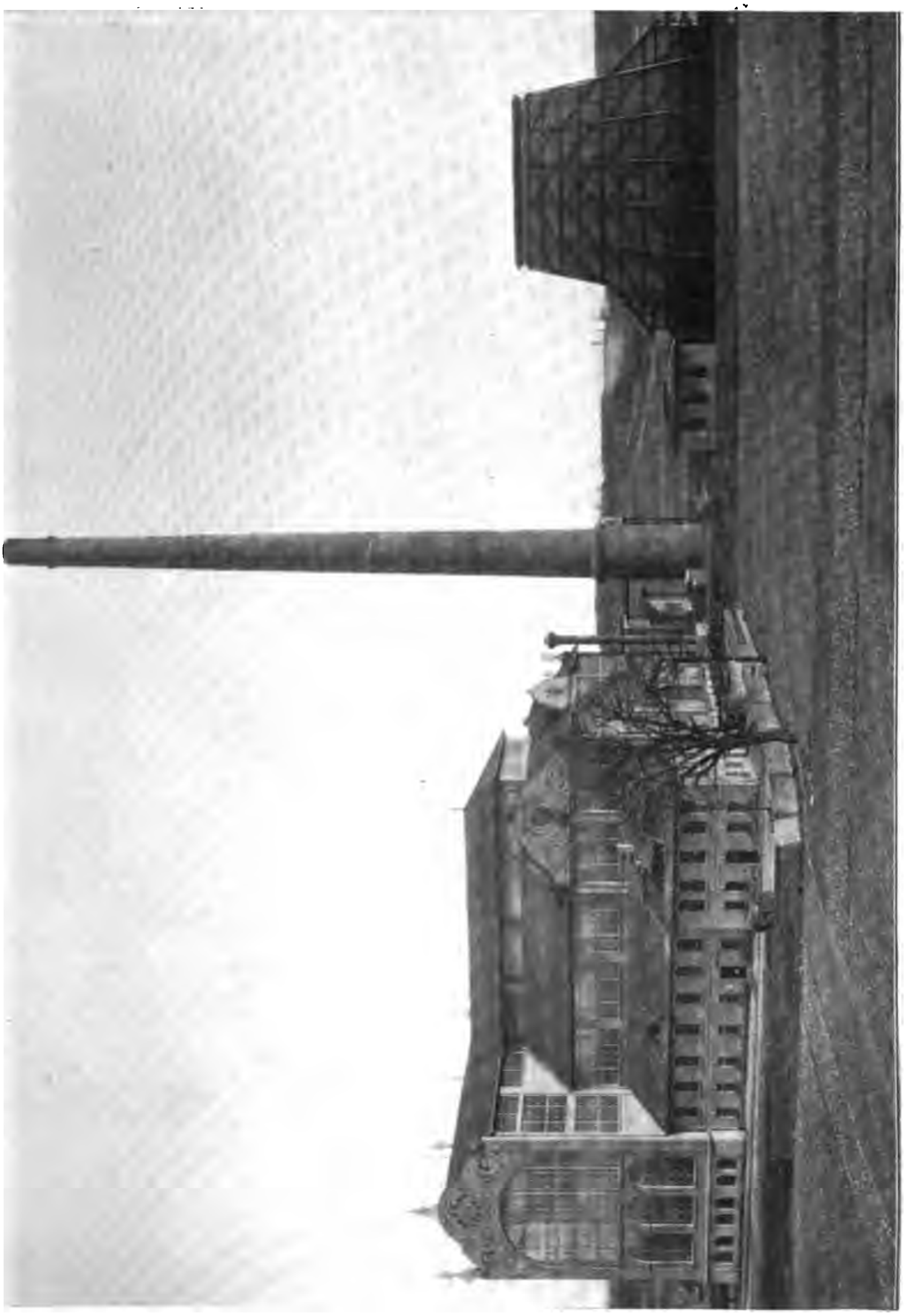


FIG. 3. Electric Light and Power Plant of City of Hanover, Germany.

One of the most remarkable power plant structures architecturally considered is that at Dresden of the plant for heating and lighting the royal and municipal buildings of the capital of Saxony. The territory to be supplied includes the fine residence

Fig. 4. High-Pressure Steam Heating Central and Lighting Plant at Dresden, Germany.

district of the city, extending along the banks of the Elbe, and as the only available situation for the power house was in the rear of the Royal Theater near the river, it was necessary for the structure to harmonize with the surrounding buildings. A medieval

style of architecture was adopted. The building is constructed of rough-faced granite coursed ashlar, with handsome pavilions at the corners; the chimney, arising from the center of the building, is concealed within a tower with a spiral staircase and heavy ornamental stone trimming. The entire plant is remarkable for its fitness to its surroundings, while typifying its purpose.

A handsome and imposing structure is that of the New York Rapid Transit Subway on West 59th Street. This structure faces properly on 11th Avenue and this façade is most elaborately treated, and the ornamental scheme is also carried along the north and south fronts. The general style of the building is what may be called French Renaissance, and the color scheme has therefore been made rather light in character. The base of the exterior walls has been finished in cut granite up to the water table, above which the walls are faced with light buff pressed brick. This brick has been enriched by the use of similarly colored terra cotta, which appears in the pilasters about the windows, in the several entablatures and in the cornice and parapet work.

All window frames and sashes are of uniform design and constructed of cast iron, and all the windows are glazed with wired glass for protection purposes. The sloping

FIG. 5. Interior of Generating Room, L St. Plant, Boston.

sides of the roofs are constructed with terra cotta blocks protected by waterproofing, and over this are laid Spanish roll tiles which are enameled a dark green on the

exposed surface. The sloping sides of the roof, directly over the operating room, are constructed of heavy glass, suitably supported on steel bars with copper trim work. Copper condensation gutters are provided, and under each section of glass is erected a wire screen.

The main doorways leading into the structure are trimmed with cut granite, and the entrance lobby in the northeast corner is finished with a marble wainscoting. The exposed wall of the operating room is faced with a light cream-colored pressed brick, with an enamel brick wainscoting eight feet high, extending around the entire operating area; the wainscoting is white, except for a brown border at the base. The office, the toilets and locker rooms are finished and fitted with marble and other materials in harmony with the general character of the building.

Two other recent American central stations also show a great advance in power plant architecture, viz., the Fisk Street station of the Commonwealth Electric Company, Chicago, Ill., and that of the Boston Edison Illuminating Company in Boston, Mass. In both of these stations the interior of the operating room is finished with enameled brick; the Fisk Street station being almost entirely white, while in Boston the white tiling is set off by green outlined panels between the pilasters. In these stations the columns of the steel frames are concealed by pilasters, between which arches are sprung below the crane runway girders; the latter being entirely hidden, the only steel work visible being that in the roof system. The room is lighted by a continuous skylight in the monitor, giving a very pleasing general illumination. In the Fisk Street station a visitors' gallery has been provided for the convenience of sight-seers. It would be easily possible to give a large number of examples on this subject, but the general points to be considered will now be taken up and discussed.

Windows and Doors. — The windows of the side walls should be to as great an extent as possible arranged symmetrically with regard to the spacing of the generator units. It is desirable to secure a large area of window surface, and the design should be well considered. Arched tops give a very handsome appearance and in some cases diamond-shape panes of glass have been used to add to the effect. The large windows should be paneled in a manner consistent with their design.

The doorways should be ornamental, massive and of suitable size, as has been previously mentioned. Oak, well paneled, makes a very handsome door, particularly when trimmed with bronze. In many cases, however, metallic doors are used, as it is desirable to avoid the naked appearance of the ordinary fireproof shutter.

Crane. — The crane may not appear an architectural feature, but even this unpromising subject may yield to suitable treatment. It should be designed to conform in a way to the roof trussing. In continental Europe lattice frame girders are often used for this purpose, very few plate or box girder frames being employed. In America and to a certain extent in Great Britain the question of first cost generally governs, instead of artistic considerations, and for this reason the unsightly fish-bellied box girder is prominently in evidence.

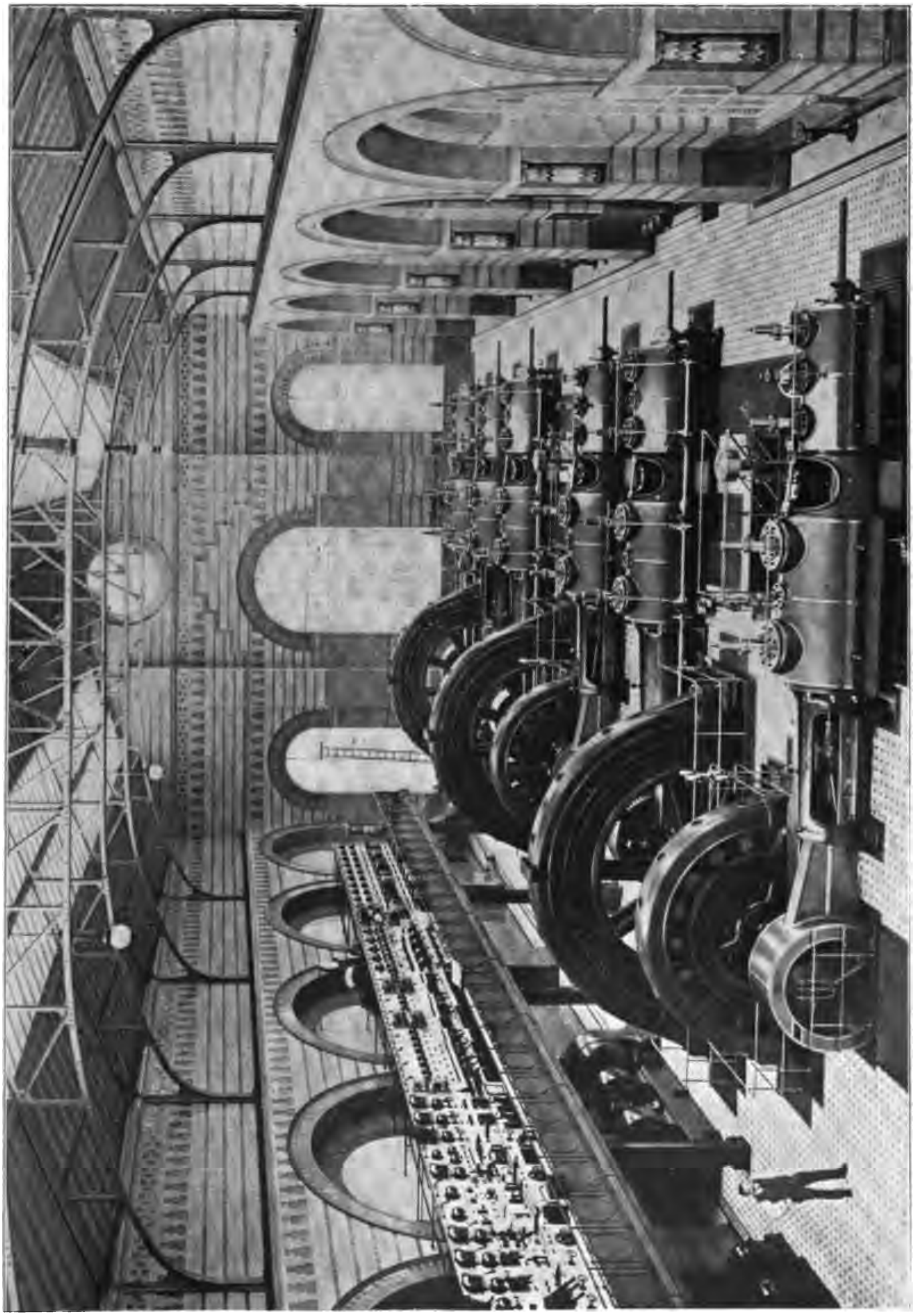


FIG. 6. Light and Power Plant of Harland and Wolff, Ltd., Belfast.

Walls. — The walls, particularly those of the operating room, should be light colored, preferably faced with glazed brick, or cement plastered and with a wainscoting of a contrasting color. Pilasters may be used to break up the monotony of a smooth surface and to conceal the steel columns if desirable. A very handsome appearance may be secured by outlining the panels between the pilasters with brick of another color. The crane girders can be concealed by a cornice supported with arches between the pilasters.

Floors. — From any standpoint a tile or mosaic floor is the most desirable, being smooth, easily kept clean and having a handsome appearance. In addition it is often the practice on the Continent to lay carpeting in the main passageways. If common cement flooring is used it should be granitoid finish to imitate tiling and well rubbed down to a smooth, even surface. The floor should in this case be of a dark color in order to render drips of oil and water inconspicuous.

Pipe Trenches. — All piping where brought through the floor should be surrounded by cast-iron thimbles, preferably extending slightly above the floor level, as previously stated. In the walls similar thimbles should be used, projecting about a quarter of an inch beyond the finished face of the wall. The wall thimbles should be provided with sheet-iron covers fitted to the pipe covering and painted to harmonize with the general appearance of the plant. The purpose of these covers is to prevent dust and dirt entering from the boiler room. Where large openings must be made in the floor for big pipes, such as the tail pipes of barometric condensers, exhaust piping, etc., it is advisable to provide a cast-iron floor plate fitting the pipe with the thimble, to prevent dirt from falling through.

The piping should, as far as possible, be kept out of the generating room. This is particularly necessary in vertical turbine plants, if a good appearance is to be considered, but this is difficult where no basement is provided, since it is necessary to group the condenser and auxiliary machinery with the main units. Such piping as is used should be run with easy bends and in as inconspicuous a manner as possible.

Galleries. — In all plants a number of galleries are required to provide means of communication and to reach different parts of large machines. While machine galleries hardly come within the province of the architect, they should be designed to conform with the other galleries and the railings throughout should be of uniform height and design. Half brass, half iron railings, while often used for their supposedly artistic appearance, are neither one thing nor the other. Brass is not a suitable material for railings; iron railings have a more substantial appearance and can be made as handsome as may be desired. The gallery plates and brackets should be uniform, it being undesirable to employ cast iron in one place and concrete or steel in another. Cast-iron plates, their top being finished in a diamond pattern, and having a slight curve around their outer edge, present a good appearance and are eminently satisfactory.

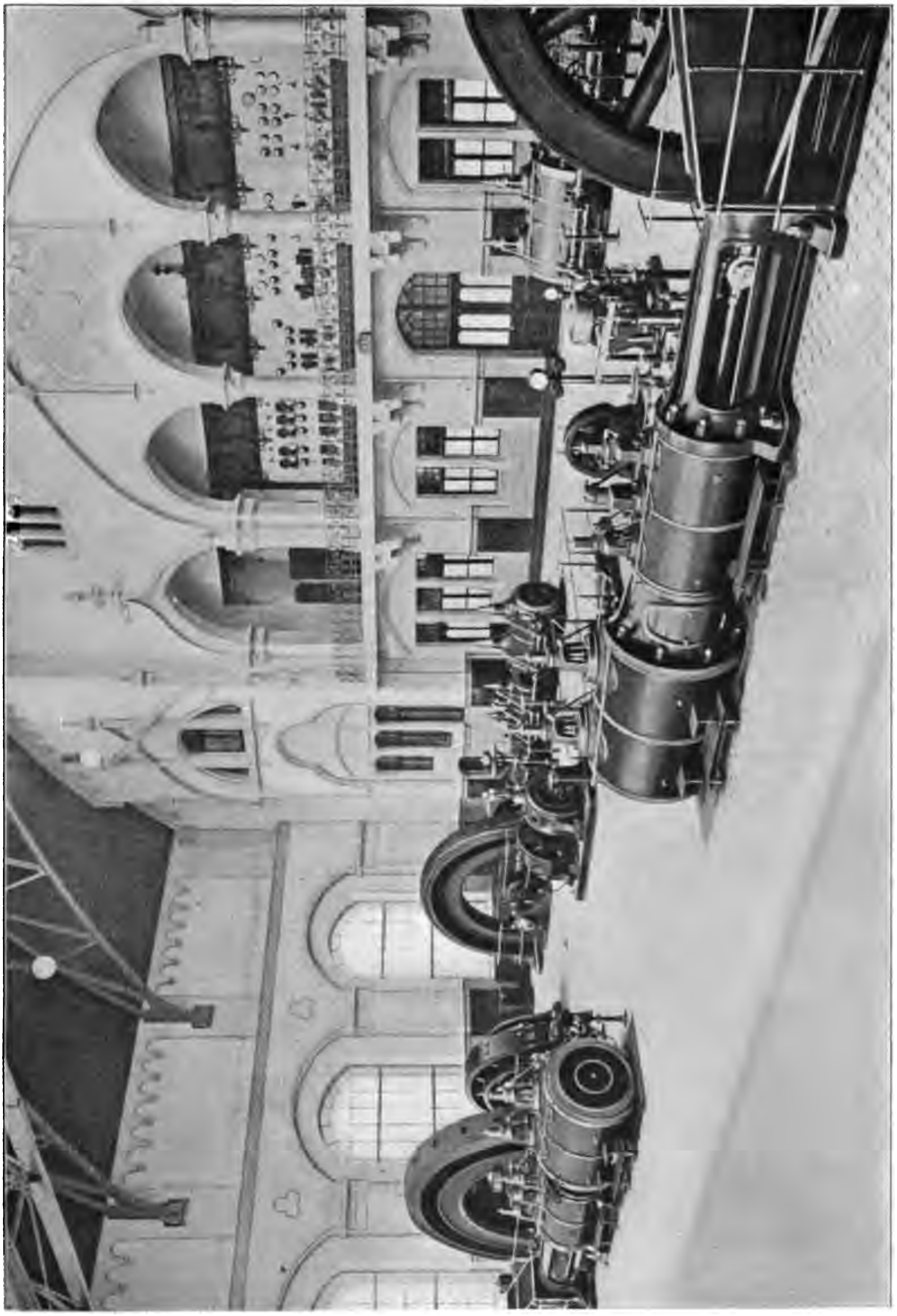


FIG. 7. Interior of the Charlottenburg Plant, Germany.

Switchboard. — In small plants it is practicable to place the switchboard at one end of the generating room, which is a very favorable location, but in plants over 10,000 horse-power the switchboard becomes so large that this location cannot be used, and it must be placed on the side of the room. The switchboard should be located in a gallery or in a special lean-to, facing the generator room. Frequently in smaller plants the switchboard structure forms the partition between generating and switching rooms. The switchboard should preferably be of a light color, principally on the score of cleanliness, and should be artistically designed in accord with the costly instruments upon it. In a few cases iron has been used for the entire switchboard, entailing considerable care in insulating. Usually slate, black granite or white marble is preferred for this purpose. The latter practice is common on the Continent, the panels being framed with dark toned ornamental metal, and by a symmetrical arrangement of the different instruments a highly pleasing appearance may be secured. The use of black granite or slate panels, without any ornamental border, is the everyday American practice. In a few cases the switchboard has been separated from the generating room by glazed partitions, in other cases simple arched openings have been employed with good effect. It is advisable to provide an extension of the gallery into the generating room, as a pulpit from which the operator can see all parts of the plant. A very handsome switchboard, artistically arranged, is that of the Charlottenburg plant. The switchboard here stands on a gallery recess in the end wall of the building, which is carried across the front of the gallery with arched openings and columns above the pilasters. The switchboard is of white marble set in a dark framing. The operator overlooks the generating room, of which every point is visible. The roof construction is designed in harmony with the appearance of the entire plant, while the floor is finished with mosaic tiling in a manner common in continental power houses.

Boiler Room. — The boiler room has not received much attention from the architect, it being considered of less importance. In continental Europe one-story boiler rooms are the rule, and for these it is possible to secure a better appearance than is practicable with the multi-storied boiler rooms used in America and Great Britain. The former rooms can be lighted by overhead skylights, and where the boiler settings are faced with white enamel brick a very light appearance is possible, in the absence of overhead bunkers. By dividing the bunker construction so as to permit a central skylight, it is possible to secure a very good boiler room, and this arrangement has been adopted in some places.

The unsightliness of most boiler rooms arises from the fact that no provisions are made to keep them clean, and cleanliness is not insisted upon. Coal should not be allowed in heaps before the fire doors, and ashes should be removed from the pit and not left in piles on the floor, as is often the case. Racks or hooks should be provided for the firing irons and tools, and their use should be insisted upon, no tools being permitted to lie about the floor or lean against the walls. The pipe covering should be painted a uniform color and smoothly finished, so that it can be kept free from dust and dirt. Suitable uniform galleries and walkways should be provided by which all

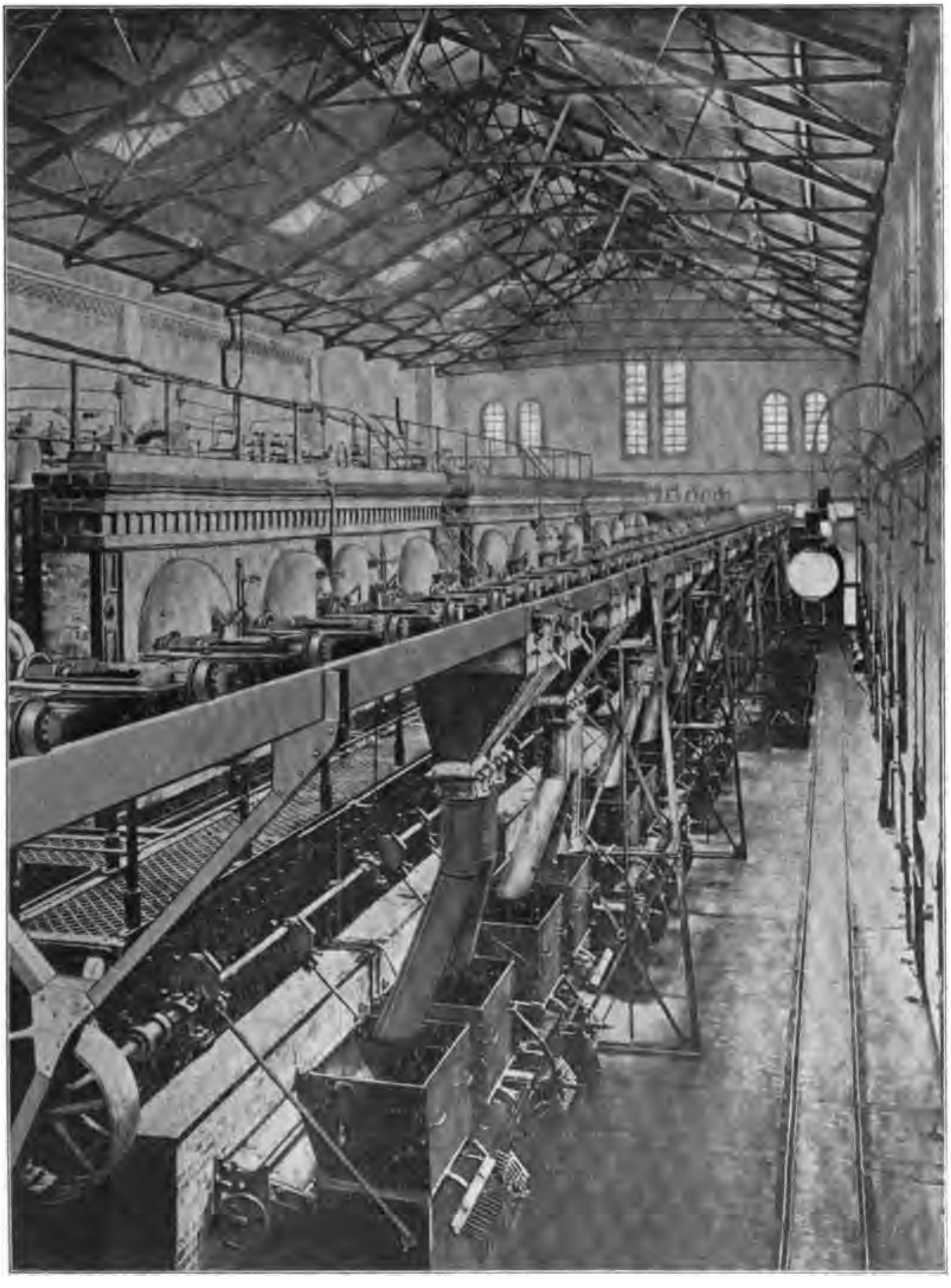


FIG. 8. Interior of Boiler Room, Municipal Plant, Frankfurt on the Main, Germany.

points can be easily reached. The walls should be whitewashed or finished in some light color and should be kept clean. It may seem impracticable to insist on spotless cleanliness in a room where coal dust is continually blowing around, but it is not impossible.

Removal of Ashes. — A portion of the boiler-room basement below the boilers or firing aisle, in plants where a basement is built, is usually reserved for the handling of ashes, soot and dirt from the boilers, provision being made for conveying it to storage bins for shipment. In some plants this is done by means of a conveyor underneath the ash hoppers, in others ash cars of about one-ton capacity running on an industrial track operated by hand labor or by a small electric locomotive. As these ashes are wet down in the ash hopper to quench them, it is necessary to provide a suitable gutter, immediately beneath the ash spouts, for conveying this water to the drainage system. The basement should not be used as a storage room for ashes. The conveyors beneath the boiler floors or the ash cars discharge into a hopper, from which the ashes are taken to the storage bin, and it is necessary to the efficient operation and the appearance of the plant that these ashes should be entirely removed, and the portion of the plant reserved for handling them should be kept clean.

The main ash hopper is preferably located adjacent to the point at which coal is received, either inside of the building or outside, in order that the empty coal cars may be utilized for the removal of ashes without shifting.

Coal Storage Plant. — The coal tower, while a very necessary portion of the plant, is badly neglected from an architectural point of view. Although it is unnecessary to attempt any elaborate treatment of this part of the plant, which would be an exceedingly difficult matter in many cases, particularly with traveling towers, the coal tower as usually designed is a steel structure, and should match the building, bearing in mind its purpose. Too often this tower is rendered very unsightly by a rough corrugated iron or wooden plank sheathing. An excellent example of the architectural possibilities in the design of a coal tower is presented by the Vienna twin municipal plant and by the two plants of the New York Central Railroad Co., one located at Yonkers and the other at Port Morris, in the vicinity of New York City, where the coal tower has been designed practically as a portion of the main building. In some cases, however, the type of the coal tower and ash bunkers is governed by local conditions and the system of conveyors installed, so that it is difficult to treat them in a manner consistent with the main structure.

In some of the smaller plants, especially in Europe, coal is stored in a building similar to the main structure, or built in the main structure as a separate room, while in the large plants open or exposed coal yards are sometimes used, owing to the large quantity of fuel which it is desired to carry in stock; but as open coal storage plants do not lend themselves to architectural treatment, it is hardly possible to do anything with an exposed plant except to keep the coal piled in fairly good shape, which is a matter in the hands of the operating executive.

Chimneys. — One of the most important parts of a plant, and a feature much neglected architecturally, is the chimney. In many plants these are of such overpowering size that the main building appears as merely a pedestal for the shaft. In many cases these chimneys do not in any way harmonize with the appearance of the building or its construction, the finish of the chimney shaft being of such a radically different design from that of the building that it reacts upon this in a detrimental manner. A large plant with one or two massive chimneys requires very different treatment from a building in which a number of smaller stacks are erected. The chimneys have such an effect on the appearance of the building that it will be desirable to arrange the window and roof construction in accord with them.

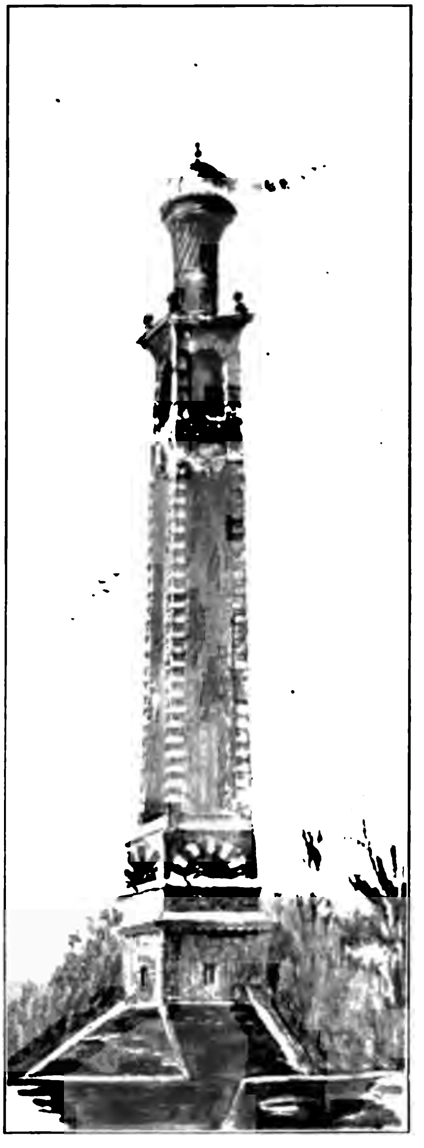


FIG. 9. Chimney of the Electric Power Plant in Munich (*from a sketch, and by courtesy of Mr. C. Stanley Peach, London*).

Conclusion. — Too much attention cannot be called to the fact that in the design of a power house the whole structure must be considered together with its surroundings to secure a pleasing appearance. Frequently the case arises that the plant is located in a neighborhood where the character of the surrounding structures may entirely govern the architectural features of the plant, it being desirable to secure a well-designed plant, and without any appearance of clumsiness. For this reason multi-story boiler plants with a parallel generating room of equal height are difficult to treat from an architectural point of view. A lower building, in which offsets can be made and the height of the structure varied to suit the different portions of the plant, offers a much better opportunity for the architect to display his skill and ability.

It cannot be expected that every plant should be architecturally treated in the same manner as the Hanover plant, or to secure the Gothic appearance of the interior of the Charlottenburg plant, and in a way such structures are undesirable on account of the expense entailed in construction, but it must always be remembered that a pleasing appearance can always be secured

without any additional expense. In fact many of the prominent plants which are notorious for ugliness have cost more for building than those which are noted for their fine appearance, a proper knowledge of architectural conditions being requisite to secure such results, which cannot be obtained by the strictly mechanical engineer.

In this present age of art and science, when engineering and architecture stand so high, it is peculiarily unfortunate that every year such a number of unattractive structures are created for the production of power, and that a greater part of the power plants in America and Great Britain are masterpieces of ugliness. The prime requisite in the architectural feature of these structures is that the design must be well considered in all points from foundation to chimney top, and the building should be typical of its purpose, viz., as that of a power plant.

CHAPTER IV.

BOILERS.

Type of Boiler. — The conditions governing the design of a boiler are of such a varying nature that it may be stated as a general truth that no standard boiler is the most efficient for the combination of circumstances other than the particular circumstances for which this standard boiler was designed. The first question to be decided

FIG. 1. Interior of Boiler Room, "Bille" Plant, Hamburg.

in the choosing of a boiler is the type of boiler to be suited to the conditions. In general we may say that the type is practically determined by the character of the load which the boiler has to carry. That is, for instance, in the case of a railroad power plant, where the load undergoes rapid fluctuations, the water-tube type will be found

to fill the conditions best, on account of the fact that it carries only a comparatively small amount of water, and hence is better adapted for rapid steaming. However, it must be borne in mind that a readily available supply of heated water is essential to the economical operation of this type of boiler. On the other hand, where the requisite supply of heated water is not available, the shell boiler will better meet the conditions imposed, on account of the fact that it has a large storage capacity. The space available for boilers may have considerable bearing on the choice of the type, hence is an important point for consideration, especially in the equipment of existing plants with new boilers. For instance, plenty of vertical space may be available whereas the floor space is limited, therefore the upright type of boiler may be found best suited to the conditions.

The volume of water contained in the water-tube boilers, as has been stated, is less than that contained in the fire-tube boilers. This, of course, is a slight advantage in favor of the fire-tube boilers, since the greater volume of water affords a means for storing superfluous heat at times when it is not required for making steam. This advantage, however, is greatly outweighed by those already shown in favor of the water-tube boilers. For this reason the water-tube boiler has been adopted for practically all modern, and especially large power plants. There are quite a number of plants in which the fire-tube boiler is used to advantage. These plants are practically all operated on comparatively low steam pressures, say up to 150 or 160 pounds. Water-tube boilers are, however, run on a pressure of 200 to 250 pounds per square inch, or even higher, as are also some shell boilers. An example of the use of very high pressure water-tube boilers was to be seen at the St. Louis Exposition, 1904. In this instance a Delaunay Belleville boiler furnished steam at a pressure ranging from 295 to 310 pounds, to a six-cylinder quadruple expansion engine of the same manufacture. This boiler contained a superheater which raised the temperature of the steam to 750° Fahr. While the above-mentioned instance of high pressure boiler was intended primarily for exhibition purposes, the writer is of the opinion that the rapidly increasing steam pressures will soon reach from 225 and higher for everyday practical use. The use of steam at 200 pounds per square inch is common practice today in modern plants in Europe, another instance of which is to be had in the Long Island City power plant of the Pennsylvania Railroad.

Safety.—The question of safety is one of the most essential requirements which the designer, constructor and user of steam boilers must consider. As can be readily understood the quantity of stored heat energy in a steam boiler is usually enormous, and if set free by the rupture of the containing vessel widespread disaster will generally ensue. The damage ordinarily wrought in such cases covers, not only the destruction of property, but is almost always accompanied by loss of life.

To secure a boiler which is safe the best material and workmanship must be employed throughout. The material needed for the purpose should be as strong, tough and ductile as it can possibly be made. Of these qualities that of ductility is perhaps the most important, since this gives the material its capability of being altered

in form without fracture. A lack of tenacity, for instance, can be met by making the material thicker, but if brittle the material will rupture with abrupt changes of form,

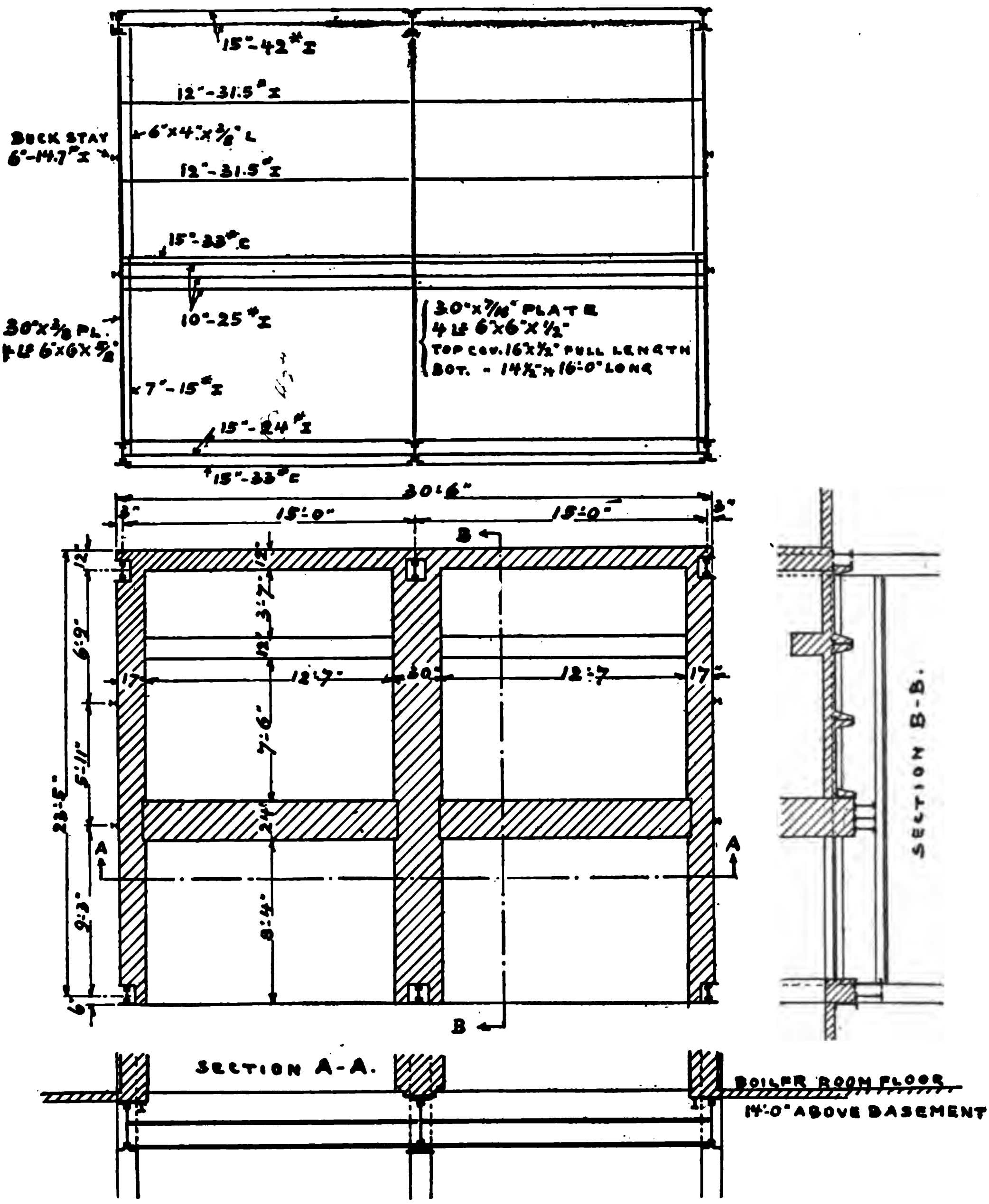


FIG. 2. Steel Work and Boiler Setting of two 604 H.P. Babcock and Wilcox Boilers.

however thick it may be made. The best boiler plate must possess great strength and must combine with this a great ductility. High elasticity of material must also be had.

Cast iron should never be employed for principal parts of a steam boiler, nor should any trust be placed in so-called semi-steel or "steel alloy."

The general construction of the boiler should be such that all parts are readily accessible for cleaning purposes, inspection and repairs in case of leaks or accidents. In the general design of water-tube boilers the small unit principle employed in the making up of the heating surface precludes the idea of immediate personal access to the inside of the tubes for cleaning and inspection. Tubes or units of such a form that they cannot be inspected inside over their entire length, or which are so curved that they cannot be properly cleaned by scrapers or cleaners, are claimed, by some authorities, to be objectionable. Some types of boilers embodying such features have other advantages which may outweigh the disadvantage due to curved tubes.

Simplicity. —The boiler to be adopted should have as few joints as possible, be of as simple design as can be made use of, as the more joints there are and the more complicated the design the greater will be the trouble in making repairs, and keeping these tight. Joints between tubes and headers, and tubes and drums are, for the most part, made by expanding the tubes. In some types of boilers hand holes with additional ground joint caps are required to give access to the tubes. The principal objection to the cap feature in boilers of this type is the multiplication of joints, which are sometimes an occasion for leakage and corrosion. Unless properly attended to these ground joints, when once they begin to leak, are soon cut by the action of the passing water, and in many instances have to be refaced. This is troublesome, requires time, and unless a large supply of duplicate caps is kept on hand may cause the closing down of the boiler.

Durability. — The construction of any boiler should be such that an even temperature may be readily maintained throughout the furnace and flues. Tubes or other parts, when exposed to varying temperatures, are liable to be cracked or strained by the uneven expansion, and the maintenance of an even temperature is also conducive to economical evaporation. Besides provisions for maintaining the temperature of the gases, it is essential that there be rapid and uniform circulation of the water in order to equalize the temperature within the boiler.

Water Circulation.—The circulation of water in a boiler is caused by a difference in temperature. Hot water, being lighter, rises and as it cools it falls to the lowest point, where it is reheated. It will, therefore, be seen that the smaller the amount of water per square foot of heating surface the more rapid the circulation.

Adequate means should be provided for the removal of steam as quickly as formed. If steam pockets, that is, formation of steam completely filling a section of the tube exist, burning and blistering will result. Ample steam space should be provided, a reservoir sufficiently large to deliver the required amount of steam, without variation in pressure, is especially a requisite in water-tube boilers.

Heating Surface. — The heating surface of a water-tube boiler, made up of water-surrounded surfaces, is, approximately ten square feet per boiler horse-power, that is,

allowing an evaporation of three pounds of water per square foot. The gases should have a free and unobstructed passage, and should travel with a uniform velocity over

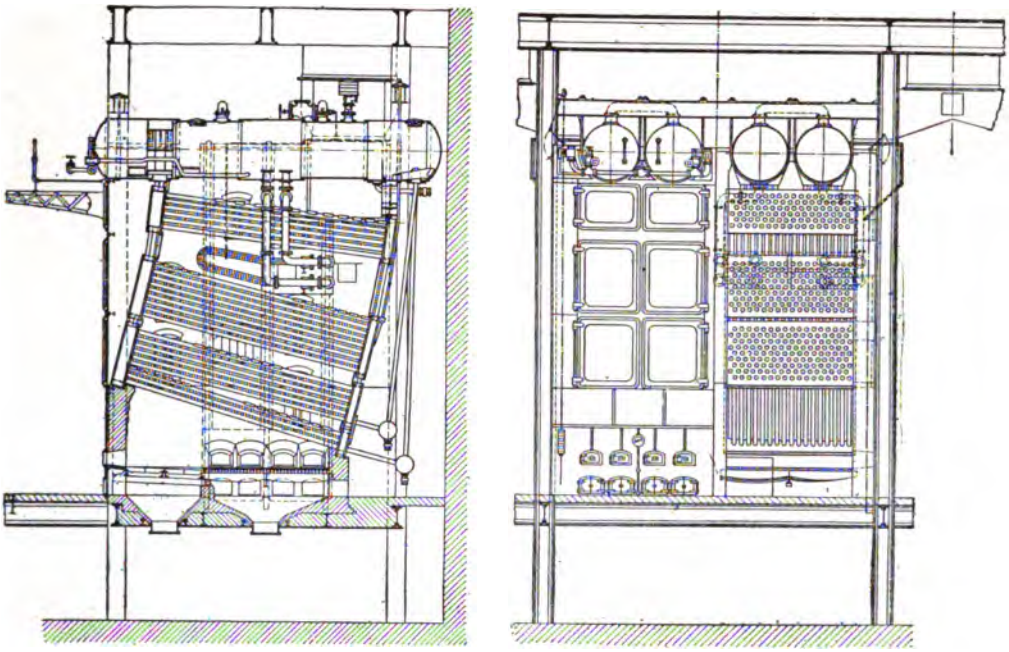


FIG. 3. Hornsby's Horizontal Boiler with McPhail and Simpson's Superheater as installed in Bow Road Plant, London. Note the two firing places, at the front and at the side, the latter is called upon for sudden overload. Heating surface of Boiler 81,000 sq. ft. Superheater 874 sq. ft. Grate area 125 sq. ft.

the entire water surface at a rate not too great, but to allow a complete absorption of heat by the water.

Grate Surface. — The grate surface should be proportioned with regard to the kind of coal to be burned. With coal of low heating value a larger grate surface is required. If the boiler setting will not allow enlargement it is then necessary to attach an extended furnace, or "Dutch oven." By doing so the length of the furnace will be increased, so that it is difficult to fire by hand, and it is usual, therefore, to use a mechanical stoker; the latter will be treated under a separate chapter.

To collect and remove soot and ashes conveniently, hoppers should be installed, provided that the boiler room contains a basement. The soot hoppers may be located directly in rear of the fire bridge, as shown in Fig. 10, and should be made of wrought or cast iron. The latter may be advantageously used, as the hopper is small. The ash hopper should extend the entire width of the boilers, so that the ashes will collect without the use of a hoe. It should be large enough to contain sufficient ashes to obviate frequent removals.

The ash hopper should be constructed of iron or steel plates. Each hopper should have two or three gates, depending upon the size of the boiler. These gates should be large enough, about 18 inches square, to prevent clogging of ashes and the use of a bar to break them up.

In order to lengthen their life, the hoppers should be lined with fireproof tile. Hoppers should not be lined with concrete, for this will crack, through the action of the hot ashes, and as these are frequently wetted, water will run through the cracks and settle between the concrete and the iron; this will corrode the iron a great deal more quickly than if there was no lining. Besides, the frequent heating of the concrete to a high temperature will cause its destruction. A better method is to do away with all iron and construct a masonry hopper, both for soot and ashes. An example of this design is shown with the description of the Vienna light and power plants.

In smaller plants the hoppers may dump directly into a trench in which there is a screw or chain conveyor.

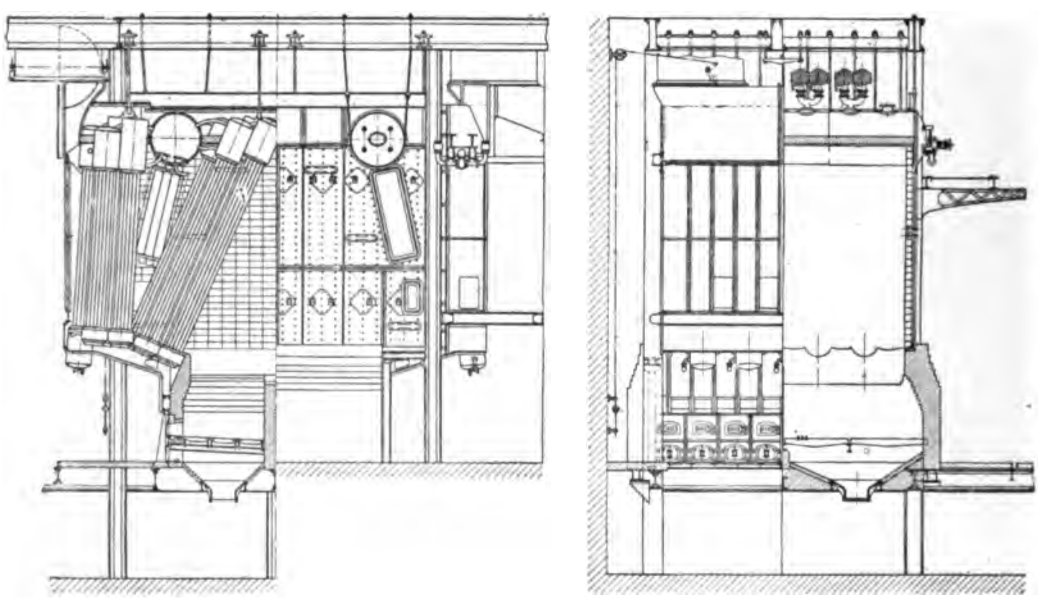


FIG. 4. Hornby's "Upright" Boiler as installed in Bow Road Plant of the Charing Cross and City Elec. Co. of London. Heating surface per boiler 10,850 sq. ft. McPhail and Simpson's Superheater 1,036 sq. ft. Grate area 168 sq. ft. Normal evaporation per boiler 33,000 lbs. per hour. A battery as shown in the Illustration is capable of evaporating 100,000 lbs. of water per hour.

Efficiency. — A boiler should be so designed that the greatest efficiency will be obtained at normal load, but if it is necessary to force the boiler the efficiency should not go far below normal. The average efficiency of a boiler is from 70 per cent to 72 per cent, although at times it will run as high as 80 per cent.

Setting. — Modern practice is to suspend certain types of water-tube boilers so that expansion may be free and unobstructed. After the boiler is set up, the brickwork is erected. To secure a satisfactory service it is necessary that the setting be constructed with the utmost care and best material, and after setting is complete it should be thoroughly dried before fire is placed under boiler.

Hard burned brick should be used for the general setting. The bond should be as perfect as possible to prevent any air leakage. All walls exposed to the action of hot gases should be lined with fire brick, bonded with fire clay; the fire clay mixed thin and the joints between bricks be made as narrow as possible. All doors should be as air-tight as is possible. The ends of the drums may be covered with a non-

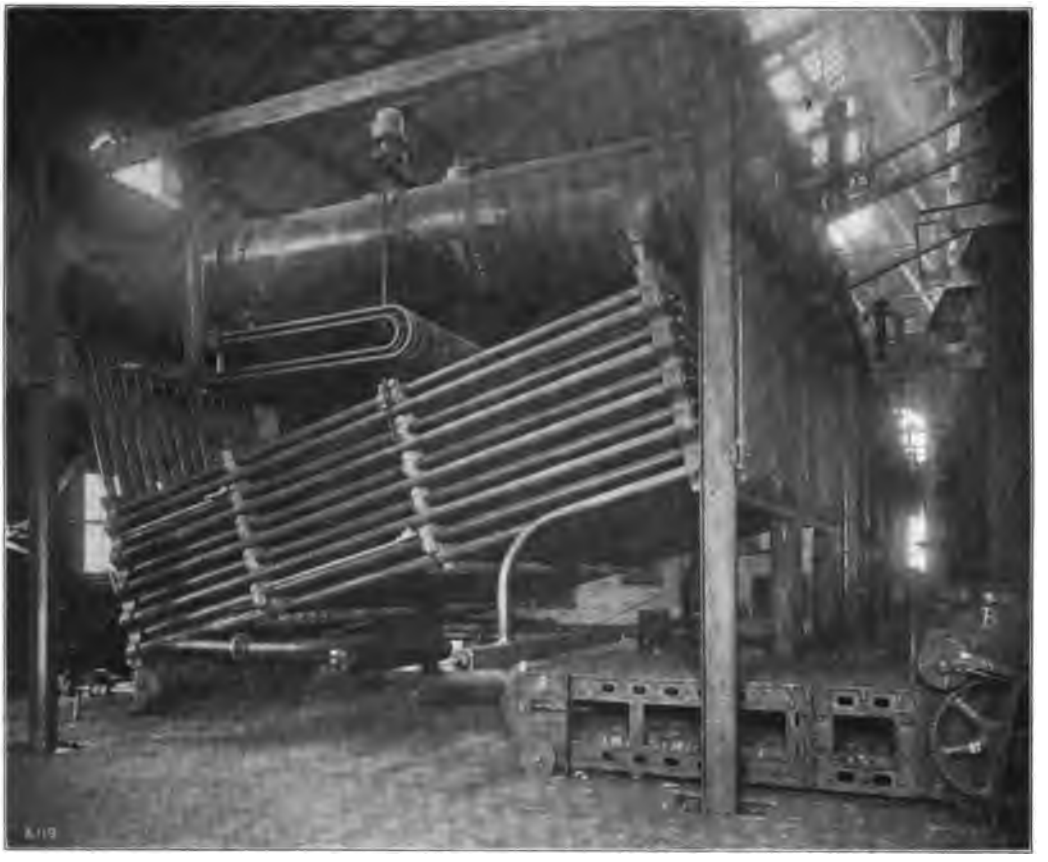


FIG. 5. 293 H. P. Babcock and Wilcox Boiler with Superheater and Chain Grate Stokers.

conducting covering, held in place with a wire netting over which is placed a coat of hard finish plaster.

A recent practice has been introduced, both in Great Britain and America, of setting the whole boiler in a steel casing which is lined with fire brick. A notable instance of this is the Bow Road station, in which boilers of 10,850 square feet heating surface are used. Another recent practice is to provide a setting embodying a

double furnace, one at each end of the boiler, which practice has also been adopted at the 59th St. plant, New York, in connection with several boilers.

Boiler walls in large power plants are usually carried on the steel work of the building, as there is a basement under the entire operating floor. An example of this is given in the accompanying illustration, Fig. 2, representing the steel work and brick setting for two 604 horse-power Babcock & Wilcox boilers, as installed for the Potomac Electric Power Company, Washington, D.C.

Trimmings. — It is necessary to provide boilers with the usual fittings, such as safety valves, water columns, gauges, etc. Safety valves may be provided with a muffler if the valves discharge directly into the boiler room, but if the steam is discharged to the roof the mufflers may be dispensed with. The steam gauges should be so located that they can be easily read from the floor. Where large boilers are used the gauges may be located 7 feet or 8 feet above the floor, or else an electric light provided.

As has already been covered in the chapter on general layout, if the boiler is of a large size it is good practice to install a gallery in front of it for convenience in operation, inspection and repairs.

The accompanying illustration, Fig. 5, gives a good view of a Babcock & Wilcox boiler before it is set. It will be noticed that these boilers are equipped both with superheater and chain-grate stokers. This particular boiler has a heating surface of 2,933 square feet, which is made up of two drums 36 inches in diameter and fourteen rows of ten tubes, each 18 feet long. There is a special header between the grates and the fire wall, in which a rapid circulation of water will be created; this will protect the fire wall from heat.

The superheater has a heating surface of 410 square feet, while the grate has 60 square feet; as this is 9 feet 3 inches long, it has necessarily to extend in front of the boiler, forming an extended furnace.

Size. — The type and various other features of boilers having been determined, the next point for consideration is the number of units and the size of each. Careful consideration must be given to the quantity of steam required at various periods in the operation of the plant. The supply required being comparatively constant, the number of units may be fewer than when the required supply varies considerably at different times. The units should be of such a number and so proportioned that the smallest amount of coal is consumed in the development of the power required for any particular period of operation, and provision should be made for any particular unit or units to be put out of service without unnecessary forcing of the other units, which condition may be imposed in the operation of the plant when various amounts of power are required to be developed and delivered, or when a particular unit is in need of repairs. For instance, in a case where five units might be determined upon as the necessary number to supply the required power, the modern practice is to install six, the additional unit being used in the interval required to make repairs on another unit, or it may also be brought into service to develop an output above the normal rating. Until recently the practice has been to limit the size of the individual unit to 5,000 or 6,000

square feet of heating surface, but some plants have been constructed or are in process of construction, both in Great Britain and America, in which the size of each unit has been increased to 11,000 square feet (see Figs. 3 and 4). In view of these facts we might say that in general the size of each unit will be as large as economically possible, considering the number of units required to make provision, as above stated, for repairs, for forcing the boilers and for varying demands upon the plant.

In regard to the size of the boiler, this is usually measured by the heating surface. American practice is to rate boilers not only by the heating surface, but as so many "boiler horse-power." One boiler horse-power being defined as equivalent to an evaporation per hour of 30 pounds of water from and at 100° Fahr. to steam at 70 pounds pressure, or equal to an evaporation of $34\frac{1}{2}$ pounds of water per hour at and from 212° Fahr. This value of a boiler horse-power was made standard by the committee of the Centennial Exposition held in 1876, and has since been incorporated in the code of standards adopted by the American Society of Mechanical Engineers. The immediate reason for adopting a value of 30 pounds instead of some other quantity was owing to the fact that the prevailing types of good engines at the time of the Centennial Exposition required about 30 pounds of steam per horse-power hour. Since the adoption of these standards the development of boiler design has been such that the conditions governing the adoption of these standards no longer prevail, owing to the fact that instead of a pressure of 70 pounds we may frequently use a pressure from 170 to 250 pounds, and even higher. Furthermore, owing to the more refined boiler-house equipment of modern times, the temperature of the feed water is considerably higher than at the time of the adoption of these standards; modern practice using water heated even higher than 212°.

Of still greater moment is the employment of superheated steam, to which condition is due the fact that steam consumption per horse-power is considerably reduced, not taking into consideration the improvements of the engines to be served. In well-designed American power plants of today one boiler horse-power actually serves from two to three engine horse-power, as shown by the accompanying table, in which the ratio between a kilowatt and the rated horse-power for various power plants is given:

BOILER HORSE-POWER PER KILOWATT

Metropolitan, New York	.66
Manhattan, New York	.83
Interborough, New York	.75
Kingsbridge, New York	.55
Waterside, No. 1, New York	.65
Waterside, No. 2, New York	.80
Port Morris, New York	.50
Brooklyn R. T. Co., New York	.71
Boston Edison Co., Boston	.82
Delaware Avenue, Philadelphia	.92

Babcock & Wilcox Boiler. — There are a number of boilers of the water-tube type on the market, all of which more or less fulfill the above-mentioned requirements. Among these, and perhaps about as common a type, both in America and Great

Britain, as any other, is the Babcock & Wilcox boiler. Primarily this boiler is composed of wrought-steel tubes, placed in an inclined position and connected with each other and with a horizontal steam and water drum. The inclined position of the tubes is used for the purpose of securing a rapid circulation of the water and consequent rapid evaporation. Vertical passages are provided at each end, between headers and drum, and usually a mud drum is connected at the end and lowest point of the boiler. The headers, which are made of wrought iron, are in one piece, and of such a form that the tubes when in position are staggered. This arrangement places each row of tubes directly over the spaces in the previous row, thus forcing the hot gases to impinge upon the surfaces of the various tubes. The tubes, which are made of wrought mild steel, are expanded into the headers at both ends; the number of tubes required depending, of course, upon the size of the boiler. For instance, a boiler of

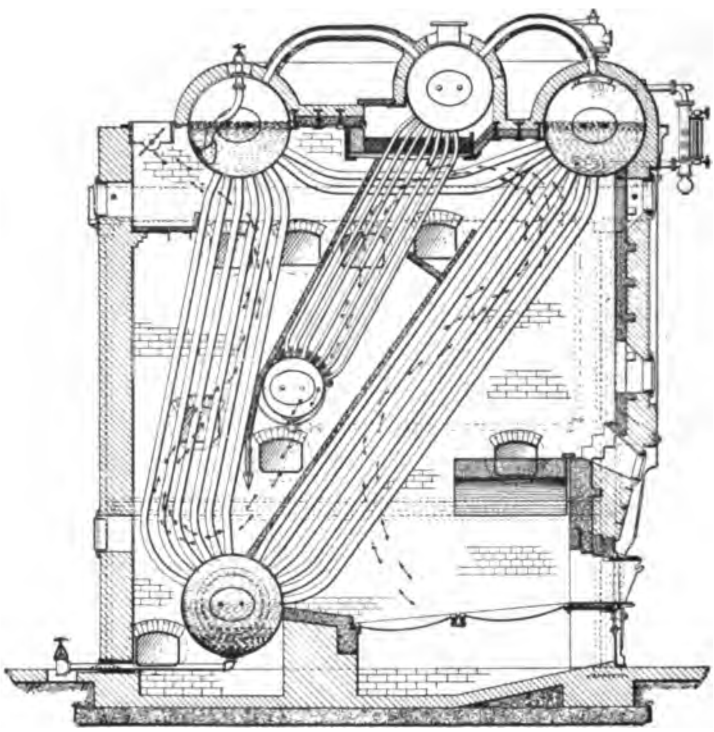


FIG 6. Stirling Boiler and Superheater.

6,000 square feet of heating surface, or commonly called 600 horse-power, employs a maximum of about 14 tubes per vertical header, and requires 21 such headers; 3 drums of 42 inches in diameter and 23 feet long would be used. The water tubes in this type of boiler are usually 18 feet long and 4 inches in diameter. At the rear of the boiler and connected with the lowest point of the rear headers is a cylindrical mud drum, provided with two 2½-inch blow-off pipes. In many instances where pure feed

water is to be had this mud drum is entirely omitted, and a small horizontal header is used in its place. The vertical sections are connected with the drums by means of short lengths of tubing expanded into the headers and drums.

Stirling Boiler.—The Stirling boiler, one of the most efficient boilers, consists of three upper or steam drums and a lower or mud drum, made of flange steel, and connected by charcoal iron or soft steel tubes. The upper drums rest in saddles and are

FIG. 7. Eight 250 H. P. Wickes Vertical Water Tube Boilers at the Plant of Philadelphia and Reading R R.

supported by a framework of "I" beams, while the mud drum is sustained entirely by the tubes connecting it with the drums above. The connecting tubes are bent slightly so as to admit of their radial entrance into the drums, which feature, together with the manner of supporting the mud drum, gives the boiler perfect freedom for expansion and contraction.

By means of baffles the furnace gases are directed along the entire length of the banks of tubes to the smoke exit in the rear. The feed water is admitted to the rear drum and follows a course of circulation opposite in direction from that of the furnace gases. In the flow downward through the rear bank of tubes a large proportion of the contained impurities precipitate and descend to the lower drum, whence they are blown out.

The boiler is surrounded on the rear and two sides by a brick setting, and the front is made either entirely of cast iron, or cast iron and pressed steel.

For cleaning and inspection purposes the setting is provided with doors located at convenient points; and access to the interior of the boiler proper is gained through a

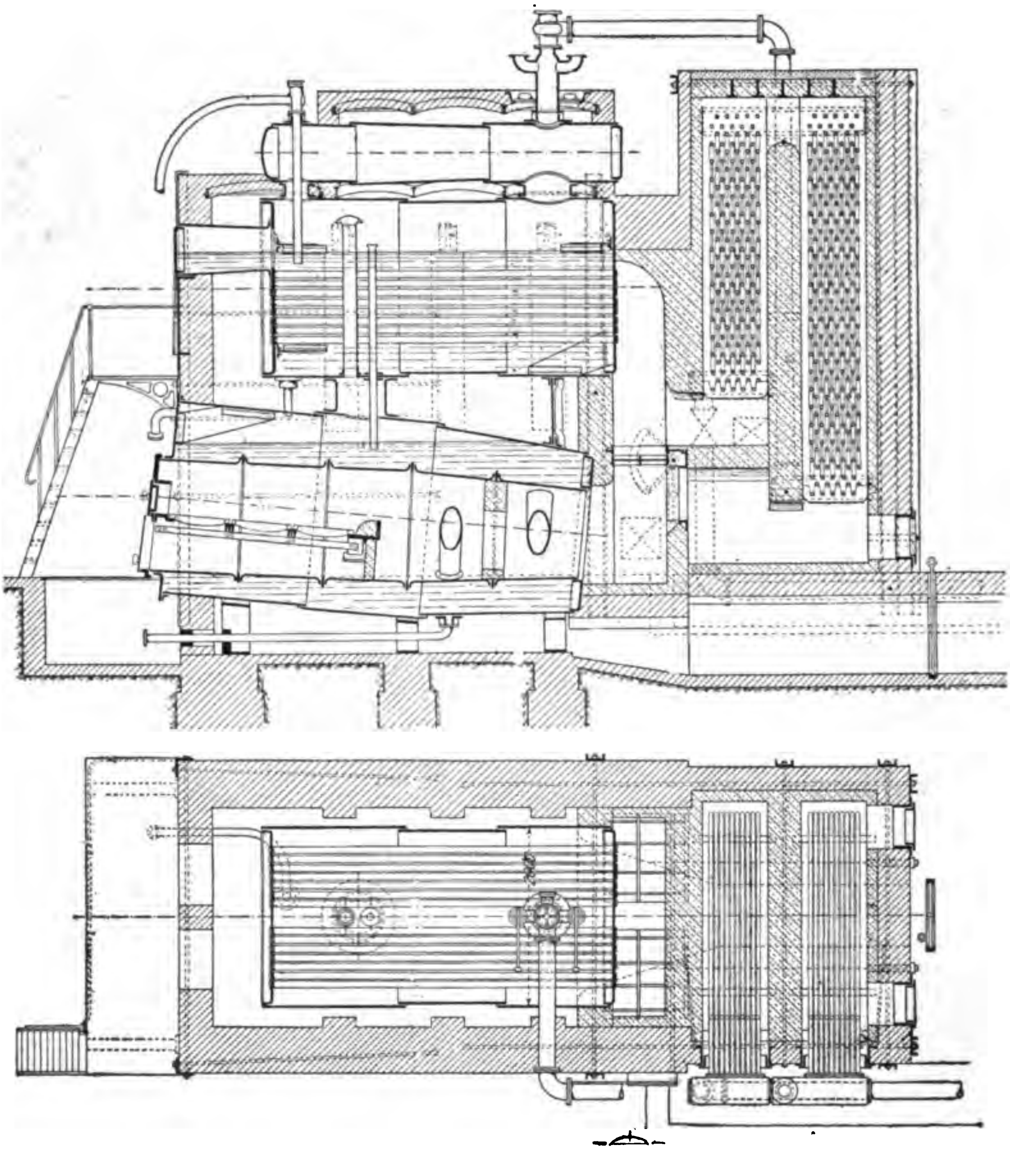


FIG. 8. Combined Lancashire and Return Tubular Boiler with Superheater attached.

manhole in one end of each drum. Ordinarily it is sufficient to flush out the interior of the tubes by means of a hose, but if the feed water is impure a turbine cleaner is used.

The furnace of the boiler is lined with fire brick on all sides, and an arched roof of fire brick is also provided, the effect of which is materially to aid in burning the fuel by radiating heat upon it and preventing the chilling effect which usually follows when fresh fuel is charged.

Wickes Boiler.—Another type of vertical boiler which is used considerably in the West, where the vertical type has been more generally adopted than in the East, is the Wickes, shown in Fig. 7. This boiler consists primarily of two cylinders, joined

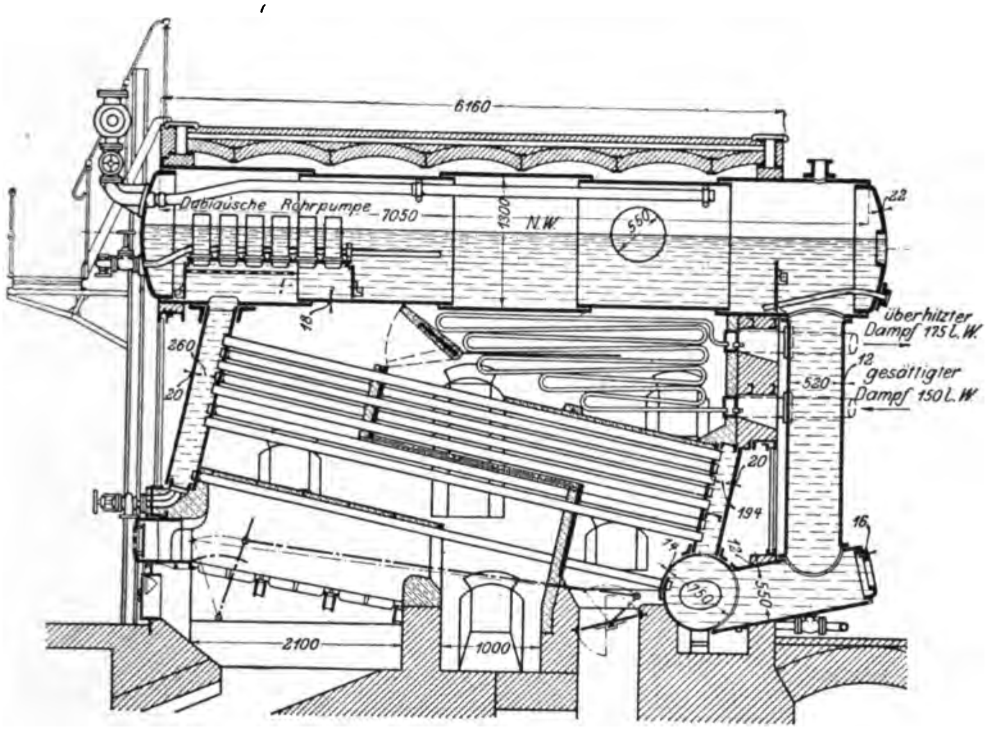


FIG. 9. Lindhaus Water Tube Boiler with Hering Superheater and Dubiau artificial water circulating apparatus. Heating Surface of Superheater $\frac{1}{3}$ of that of Boiler.

together by straight tubes, and divided by a fire-brick tile passing through their center and dividing the boiler into two compartments. The whole is then erected in a vertical position and surrounded by brickwork. The two cylinders are duplicates in their diameter and general construction, but differ in height and arrangement of convex heads.

The fire-brick dividing wall or baffle plate gives the gases of combustion two complete sweeps through the entire length of the boiler, and the second sweep from above downward. The heat in its double passage surrounds completely and closely the tubes in both compartments. The water line in the boiler is maintained, in the steam drum, at a sufficient height to insure the complete submersion of the tubes.

On a level with the water line, and extending over the tubes in the front compartment, is the baffle plate, which deflects the rising water, commingled with its steam, directly to the "downcomers."

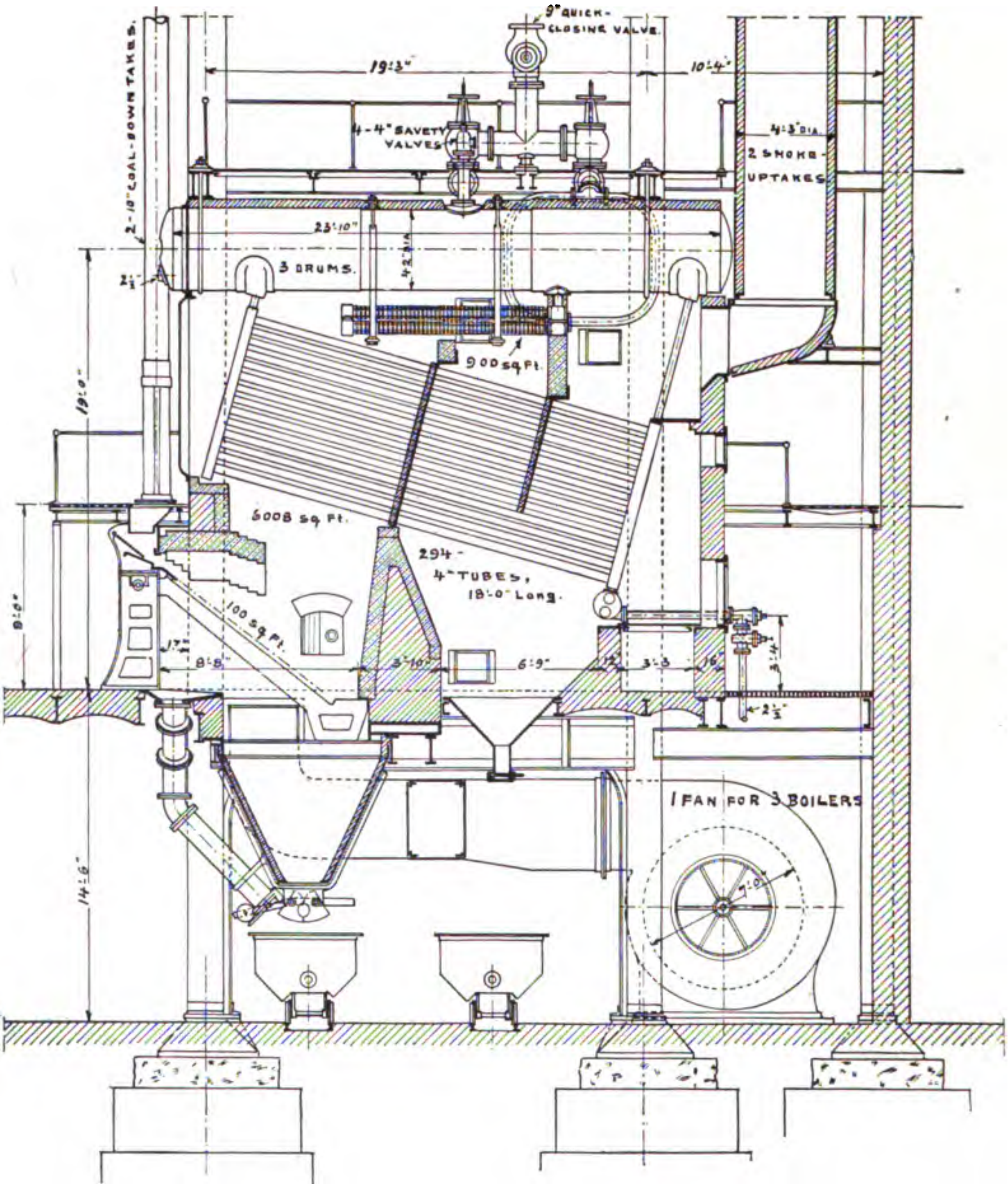


FIG. 10. Boiler Unit of the 59th Street Plant, New York. B. & W. Boiler, Forster Superheater and Roney Stoker.

The setting of the boiler is of brickwork, arranged so that it is entirely independent of the boiler and free to expand and contract, and to allow the boiler to do the same.

The foundations are so designed that, by means of a door through the circular brickwork, a man can enter underneath the boilers, examine or adjust the blow-off pipes and rivets, and see that the bottom of the mud drum is kept painted.

Foreign Types of Boilers. — The foregoing represent but three types of boilers. There are, however, both in America and Europe, a variety of types and designs successfully employed in central stations. For example, a boiler very popular on the Continent of Europe is shown in Fig. 8. This boiler is a combined Lancashire and return tubular, with a superheater attached. An illustration, showing the boiler room of the light and power plant "Bille" in Hamburg, in which these boilers are used, is given in Fig. 1.

An interesting type of German water-tube boiler is seen in Fig. 9. This boiler is equipped with Hering superheater, having a heating surface one-third that of the boiler. It will be noticed that an arrangement is provided for by-passing the superheater. At the front, in the steam drum, there is installed a Dubiau artificial water circulating apparatus. It consists of a number of tubes extending above the water line, the rising water from the front header spills over the tops of these tubes, thereby creating a more rapid evaporation.

Conclusion. —Whatever type of boiler be adopted, either tubular or water-tube, vertical or horizontal, the unit should be compact, in order to prevent unnecessary loss of heat from leakage and radiation and also for economy of floor space. The superheater, when installed, should occupy suitable space in the hot gases. This may be done without increasing the height or width of certain boilers, still having the required amount of surface to produce the proper temperature. This can easily be accomplished, as may be seen in Fig. 9, where the small tubes of which the superheater generally consists are bent to suit the condition. The heating surface of the superheater amounts to one-third that of the boiler.

Where economizers are installed they should be arranged as close as is possible, in order to have the benefit of the hottest gases. Accessibility, however, is a feature which should not be overlooked.

MECHANICAL STOKERS AND GRATES.

Advantages and Disadvantages. — Mechanical stokers are employed, first, to dispense with the services of expert firemen; secondly, to give more uniform temperature throughout the furnace; thirdly, to reduce the coal consumption.

The first item is of great importance, where skilled labor is scarce; while where skilled labor is easily obtainable and coal is expensive, it is, in the opinion of the writer, preferable not to use mechanical stokers. The second item is undoubtedly in favor of the mechanical stoker, for with hand firing it is impossible to prevent chilling of the boiler when the fire doors are open. The reduction in coal consumption may only be secured where unskilled labor is employed as above mentioned. A boiler may be much more economically forced by hand than with a mechanical stoker. It is frequently claimed that mechanical stokers may be forced for a 70 to 100 per cent

overload; in a case like this, the stokers have evidently been designed too small for their work, for no boiler should be forced to this extent.

Another important claim is that the combustion is more complete than with hand firing; this is due to the fact that the fire is continually stirred by the movement of the bars, and ashes are removed as fast as formed, giving a free supply of air. A good assistance in preventing smoke is the coking arch, with which practically all mechanical stokers are equipped. These arches may also be employed with a hand-fired furnace with practically the same result. Where it is the intention to prevent smoke, heated air may be supplied to the furnace, over the fire, at a point where the

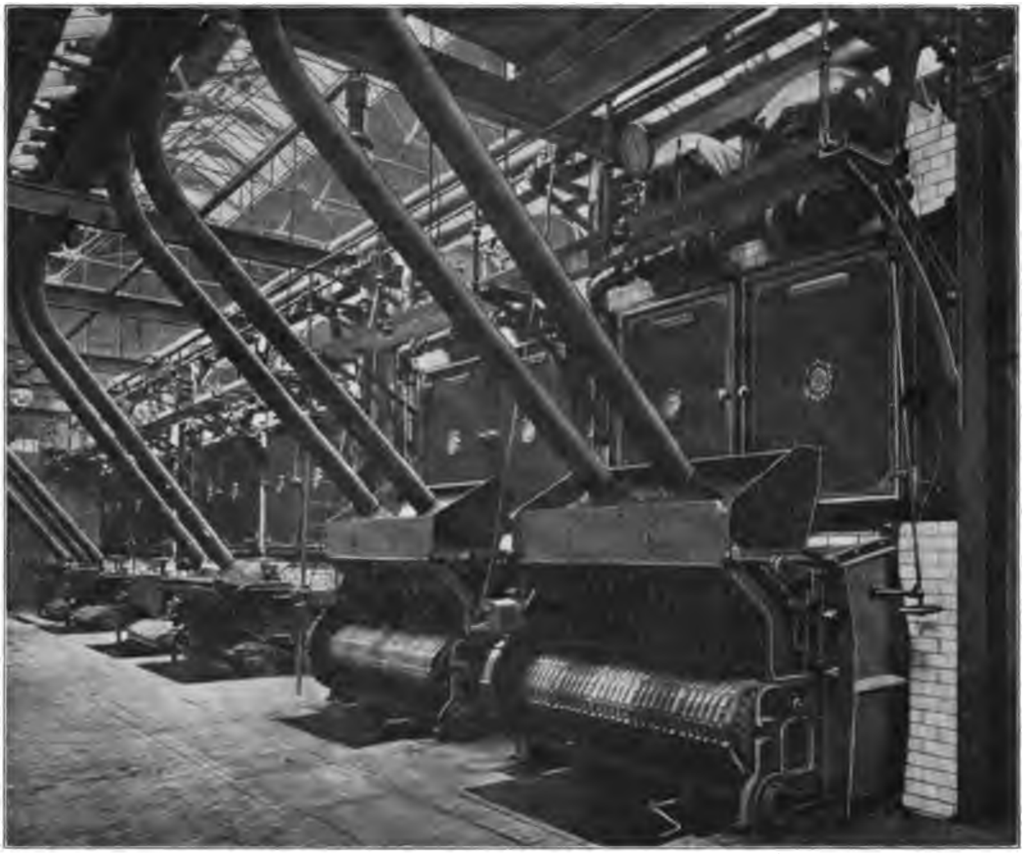


FIG. 1. Interior of Boiler Room, Stuart Street Plant, Manchester.

smoke passes between the coking arch and the fire bridge. In some instances steam is admitted over the fire to induce air to flow in; this may result in preventing smoke with suitable conditions. Steam is in some cases discharged under the grate to prevent the formation of clinkers and, of course, will add to the operating cost. In place of a device of this kind, an efficient steam blower would produce better results with but slight additional cost of operation.

Systems of Stokers. — Mechanical stokers may be classified as

CHAIN GRATES. INCLINED GRATES. UNDERFEED.

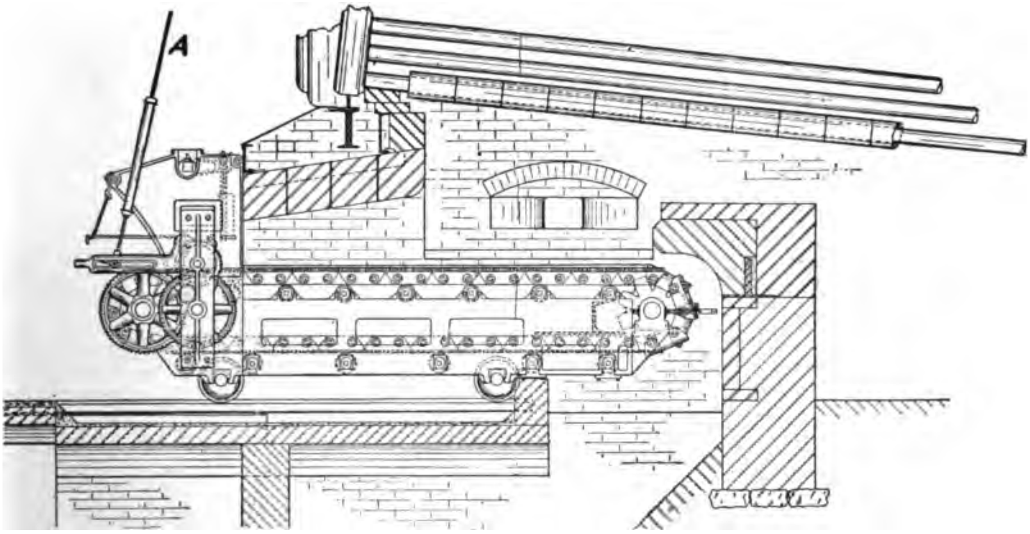


FIG. 2. Green Travelling Link Grate.

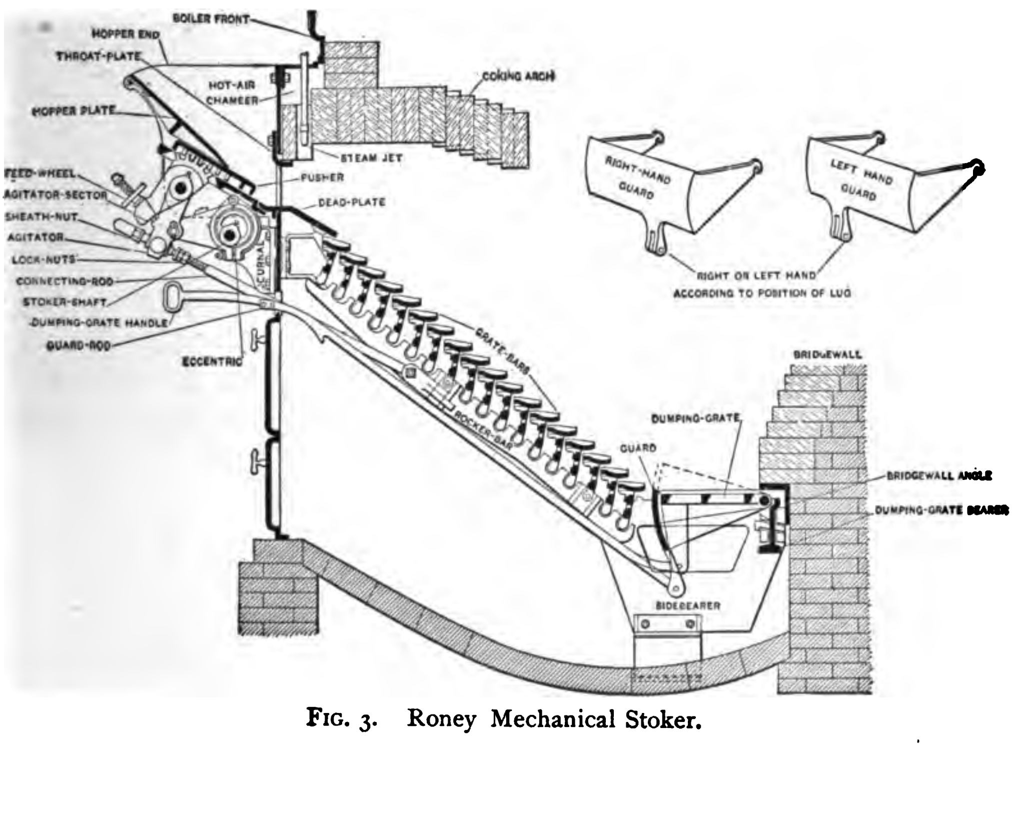


FIG. 3. Roney Mechanical Stoker.

Chain grates receive the coal at the front of the furnace, and travel slowly towards the fire bridge, where the ashes are dumped. The chain is endless and cleans itself. In the accompanying illustration, Fig. 2, which represents the Green traveling link chain, it will be seen that only one-third of the chain, nearest the fire bridge, extends over the ash pit, while the remainder is suspended over the low pit, which collects whatever coal may fall through the grate. This coal has to be removed as in all other overfeed mechanical stokers and shoveled by hand into the receiving hopper, which is seen at the left of the illustration. The rod "A" is operated by an eccentric on the shaft above the boiler, and transmits motion to the mechanism of the grate. A number of boilers may be operated by one engine. The grate is readily removable; it is sup-

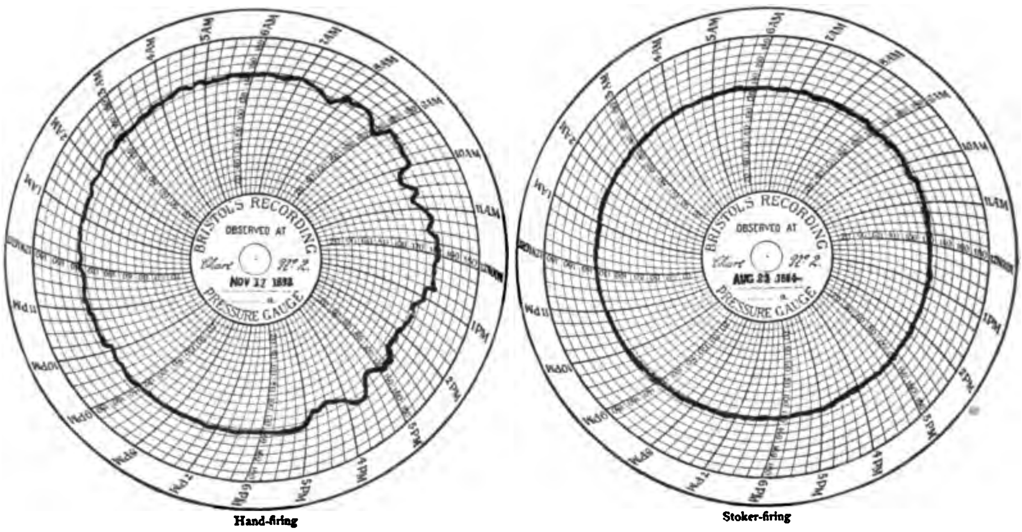


FIG. 4. Steam Pressure Diagram, Boiler fired by Hand and Mechanical Stoker.

ported on a wheeled frame and may be entirely pulled out for inspection and repairs, which is unquestionably a great advantage.

A type of mechanical stoker also frequently used is the Roney, of the inclined type. This grate is also operated from a shaft connected to several grates. The illustration, Fig. 3, shows that the grates have an oscillating motion. The ashes are dumped at the lowest point or dumping grate. Fig. 4 shows two recording gauge charts, that on the left recording the steam pressure while the boiler was hand-fired, and that on the right from the same boiler, after being equipped with a Roney stoker.

When employing overfeed mechanical stokers it is necessary to provide a receiving device for the fine coal falling through the grate, so that this may be saved. It is claimed that this coal may amount to 5 per cent of the entire amount consumed, the percentage varying with the size of coal burned and type of grate. Where boilers of from 500 to 600 horse-power have been installed, it takes one man to clean up the coal falling through the grates of six boilers.

The underfeed stokers, of which the "American" and "Jones" are the more prom-

inent, operate by forcing the coal on the grates. The "American" uses a gimlet-pointed large screw, thus forcing the coal gradually upwards, distributing on both sides of sloping grates.

The "Jones" stoker is operated by a steam-actuated piston, which forces the coal

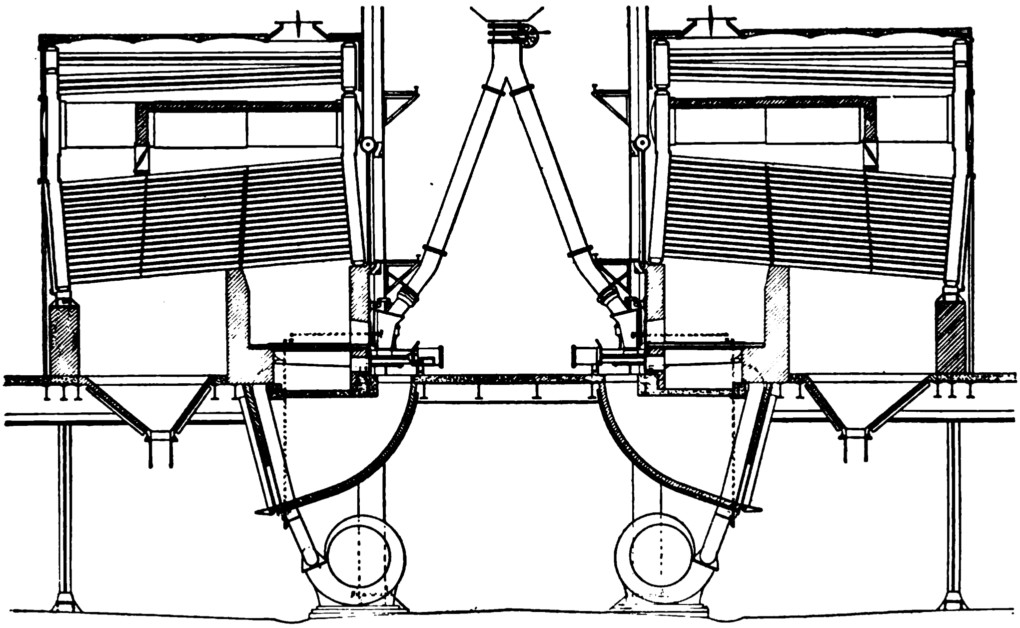


FIG. 5. Jones Underfeed Stoker at the Commerce Street Plant Milwaukee.

directly on the grates under the fire. This plunger may be operated automatically or by hand. Fig. 5 represents the application of the above-mentioned stoker to water-

FIG. 6. McClave Grate.

tube boilers in the Commerce Street plant of the Milwaukee Electric Railway and Light Company. The coal may be fed to mechanical stokers, either from overhead bunkers through chutes, as seen in Fig. 5, or shoveled into hoppers by hand.

The motive power supplied to a mechanical stoker is usually steam; one shaft may operate several boilers; if a single stoker has to be cut out the mechanism is unlinked. In selecting a stoker the kind and size of coal to be used should first be determined, so that the amount of coal falling through the grate will be minimized.

Grates. — For hand firing there are two styles of grate commonly used; viz., stationary and shaking grates. The latter is shown in Fig. 6, which represents a McClave

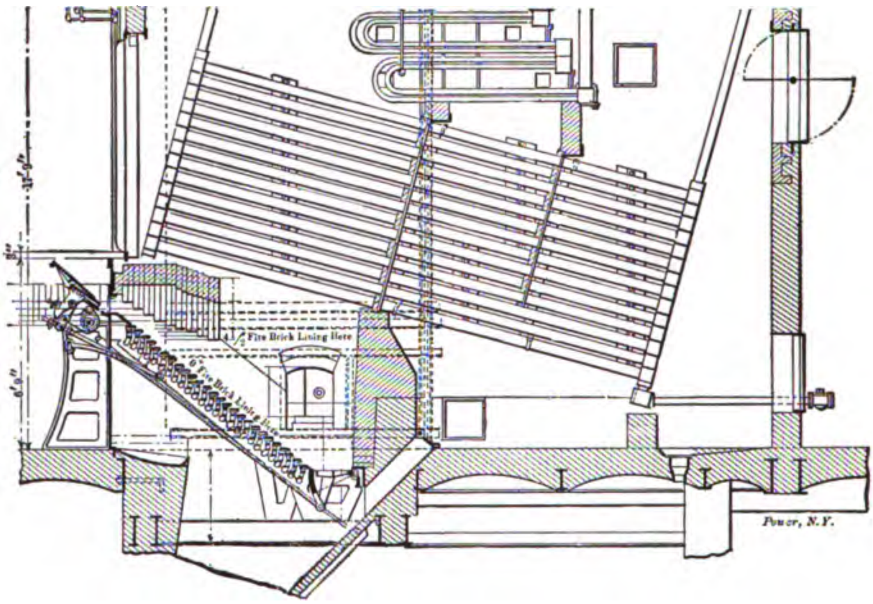


FIG. 7. Furnace Setting with Roney Stoker, note receptacle for collecting fine coal and soot chute. Port Morris Plant, New York.

grate. The grate bars are connected in groups, which may be separately shaken or dumped. The operation of cleaning fires is as follows:

The hot coal is first pushed to the rear of grate, leaving the front covered with ashes; the front section is then dumped, depositing ashes into ash pit. The fire is then pulled upon the front section and the same operation is performed with the rear section, the fire is then redistributed. Stationary grates are too well known to require description.

COAL.

Introductory. — Coal should be intelligently selected on the basis of its cost per heat unit contained, instead of on its cost per ton. Coal is the fuel most extensively used, it being the most widely distributed fuel, and the most convenient for the purpose. It is a fossil of vegetable origin, and the variations in its nature are attributable to the variations in its origin. Coal from the same seam does not vary very greatly in its nature or characteristics, and generally these characteristics are the same for all coal mined in a certain district, but at the same time the thermal value of the coal

from the same mine may vary greatly. For this reason it is important that the heat value of each shipment of coal should be determined, whether from the same mine or from the same district. As a general rule the commercial designation of the coal is based on the district in which it is mined.

From a chemical point of view coal is divided into two main classes, anthracite and bituminous. Anthracite is a word of Greek origin, meaning carbon or coke; the fuel being so called probably because it is that which contains the largest percentage of fixed carbon. Bituminous is of Latin origin, meaning containing or resembling pitch or bitumen. There are a number of degrees in the nature of these two qualities of coal, which are graded commercially as semi-bituminous, gas or cannel coals and lignites. A designation is also made of semi-anthracite. Some of the coals are very soft, while others are of a hard nature; the most recent formations or lignites being the softest, and very often the classification is made of "hard" and "soft" coal in place of anthracite and bituminous. Anthracite coal is supposed to be the oldest and deepest coal formation in existence. The veins exist principally in the United States of America, and also to some extent in South Wales in the neighborhood of Swansea; in some parts of Scotland and in some parts of France, in the neighborhood of Grenoble; in the south of Russia and in the Osnabruck district of Westphalia, Germany. The semi-anthracite or semi-bituminous coal is largely found in the central portions of Pennsylvania and some of the Western States of America; enormous fields of it exist in Wales, it being often called "Cardiff" or "Welsh" coal. It is also found in Belgium. Hard bituminous or cannel coal is principally used for the making of gas, rarely for generating steam. It is mined in the Midlands and in Lancashire in England; in West Virginia, America; to some extent in Australia, and in a few localities on the Continent of Europe. Soft or bituminous coal is the most widely distributed, with the possible exception of lignite. Extremely large fields of coal exist in Scotland; in various portions of England; in the Ruhr coal district, Germany; in the north of France; in Australia, Russia, the United States, New Zealand and a number of the Asiatic countries. Lignite is distributed very widely, but is not used largely for fuel, except in the immediate vicinity of the places where it is produced, being usually a poor quality and filled with refuse, and it is hardly considered as fuel for a modern power station. Bituminous coal can be separated into two classes, the coking and the non-coking coals; the distinction being that the coking coals when heated conglomerate into a pitchy mass, from which the volatile products are gradually distilled, previous to the combustion of the fixed carbon; while the non-coking coals disintegrate and break up in burning.

Heat Value. — The accompanying table, as given in "Steam" of Babcock & Wilcox, Ltd., London, indicates the principal components, and the heating value of the various commercial coals produced, which are burnt under boilers. It is obvious that sharp lines of demarcation cannot be drawn between the various kinds of coal; that is, each classification is only approximate, and one form gradually merges into the other.

TABLE I.—HEATING POWER OF COALS OF ENGLAND, UNITED STATES, GERMANY, FRANCE, BELGIUM, AUSTRIA-HUNGARY, AUSTRALIA, JAPAN AND TRANSVAAL.

Coals, Locality of Beds.		B.T.U.	Calories.	Nature.
GREAT BRITAIN.				
Ebbw Vale, 1848	Welsh Coals.	16,214	8,998	Almost pure Anthracites, having 84 to 89 per cent of carbon.
Powell Duffryn, 1848	Welsh Coals.	15,715	8,710	Almost pure Anthracites, having 84 to 89 per cent of carbon.
Graigola, 1848	Welsh Coals.	14,689	8,152	
Llangennech, 1848	Welsh Coals.	14,998	8,318	Smokeless steam coal.
Llangennech, 1871	Welsh Coals.	14,964	8,305	" "
Nixon's Navigation		15,000	8,325	Called smokeless.
Gwaun Cae Gurwen		15,123	8,402	Pure hard Anthracite.
Newcastle		14,820	8,225	Bituminous coal, having 77 to 82 per cent of carbon.
Derbyshire and Yorkshire		13,860	7,692	Bituminous coal, having 77 to 82 per cent of carbon.
Lancashire		13,918	7,724	Bituminous coal, having 77 to 82 per cent of carbon.
Scotch		12,870	7,150	Bituminous coal, having 78 per cent of carbon
UNITED STATES.				
Pennsylvania		14,221	7,892	Anthracite, having 88 per cent of carbon.
Pennsylvania		13,143	7,293	Cannel coal.
Pennsylvania		13,155	7,301	Bituminous coking.
Kentucky		14,391	7,987	Bituminous coking.
Kentucky		15,198	8,434	Cannel coal.
Kentucky		9,326	5,175	Lignite (good).
Illinois		13,123	7,283	Bituminous coking.
Indiana		14,146	7,851	Bituminous coking.
Indiana		13,097	7,268	Cannel coal.
Virginia		13,100	7,270	Bituminous coking.
Arkansas		9,215	5,114	Lignite (good).
GERMANY.				
RHENISH PRUSSIA.				
Dortmund	Ruhr. Coal.	14,518	8,066	Cannel coal.
Witten	Ruhr. Coal.	15,125	8,403	" "
Bochum	Ruhr. Coal.	13,514	7,508	" "
Bommern	Ruhr. Coal.	13,212	7,340	Short flame coal, Semi-anthracite.
Essen	Ruhr. Coal.	14,985	8,325	Cannel coal.
Saar-Coal		11,511	6,395	" "
SAXONY.				
Zwickau		11,964	6,647	Cannel coal.
Hohndorf		11,343	6,302	" "
Oelsnitz		10,674	5,930	" "
LOWER SAXONY, ANHALT & BRUNSWIG				
Unseburg		5,769	3,205	Brown coal or lignite, low grade.
Atzendorf		6,444	3,580	" " " "
Neudorf		6,093	3,385	" " " "
Görzig		3,852	2,140	" " " "
Halle a. S.		4,165	2,314	" " " "
Bitterfeld		3,830	2,128	" " " "
Naumburg		4,563	2,535	" " " "

TABLE I. — *Continued.*

Coals, Locality of Beds.	B.T.U.	Calories.	Nature.
Hanover.			
Osnabrück	10,789	5,994	Semi-anthracite, low grade.
Obernkirchen	12,718	7,066	Bituminous.
Silesia (Prussia).			
Carlssegen	10,422	5,790	Long flaming, Semi-bituminous.
Myslowitz	10,758	5,977	" " "
Waterloa	11,412	6,340	" " "
Königshütte	12,247	6,804	" " "
Paulusgrube	12,425	6,903	" " "
Waldenburg	12,637	7,021	" " "
Brandenburg	12,193	6,774	" " "
Neurode	13,393	7,441	" " "
Freienstein	9,651	5,362	" " "
Maxgrube	10,087	5,604	" " "
Bavaria.			
Hanshamer coal	9,821	5,456	Lignite or brown, low grade.
Peipenberg	8,186	4,548	" " "
Penzberg	8,921	4,956	" " "
FRANCE.			
Anthracite de la Mayenne	15,566	8,646	Anthracite.
Anthracite de Lamure (Isère)	13,782	7,657	"
Bassin du Bas-de-Calais.			
Marles	14,175	7,875	Bituminous hard coal.
Bully	15,120	8,400	" hard coal.
Hessin	15,352	8,529	" coking.
Lens	15,258	8,477	" hard coal.
Naux	15,256	8,476	" coking.
l'Escarpelle	15,400	8,556	" coking.
les Courrières	14,265	7,925	Semi-bituminous coal.
Bassin de la Saône.			
Blanzy	13,127	7,293	Semi-bituminous coal, long flame.
Epinac	14,086	7,826	Bituminous coal, long flame.
Bassin de la Loire.			
Rive-de-Gier, puits Henry	15,481	8,601	Bituminous hard coal.
Rive-de-Gier, No. 1	15,472	8,596	" "
Rive-de-Gier, Cimetière 1	14,493	8,052	" " long flame.
Rive-de-Gier, Cimetière 2	15,309	8,505	" " "
Rive-de-Gier, Couson	14,770	8,206	" " "
Bassin de l'Aveyron.			
Lavaysse	14,630	8,128	Bituminous hard coal, long flame.
Céral	13,203	7,335	Semi-bituminous coal.
Bassin d'Alais Rochbelle	15,643	8,691	Bituminous coking.

TABLE I. — *Continued.*

Coals, Locality of Beds.	B.T.U.	Calories.	Nature.
Bassin de Valenciennes.			
Denain Fosse Renard	15,244	8,469	Bituminous coal, long flame.
Denain Fosse Lelvet 1	15,100	8,389	" "
Denain Fosse Lelvet 2	15,316	8,509	" "
St. Wast, Fosse de la Réussite	15,105	8,392	" " short flame
St. Wast, Grande Fosse	15,188	8,438	" " "
St. Wast, Fosse Tinchon	15,082	8,379	" " "
Anzin Fosse Chauffour	14,353	7,974	Bituminous coking.
Anzin Fosse la Cave	14,549	8,083	" "
Anzin Fosse St. Louis	15,397	8,554	" "
Fresne, Fosse Bonnepart	15,228	8,460	Semi-bituminous coal.
Vieux-Condé Fosse Sarteau	15,409	8,561	" "
BELGIUM.			
Bassin de Mons.			
Haut-flenu	14,576	8,098	Semi-bituminous hard coal.
Belle et Bonne, Fosse No. 21	14,326	7,959	" " "
Levant du flenu	14,508	8,060	" " "
Couchant du flenu	14,446	8,037	" " "
Midi du flenu	14,553	8,085	" " "
Grand-Hornu	14,943	8,302	" " "
Nord du bois de Bossu	14,407	8,004	" " "
Grand-Buisson	14,877	8,265	" " "
Escouffiaux	15,217	8,454	" " "
St. Hortense, bonne veine	15,107	8,393	" " "
Bassin du Centre.			
Haine St. Pierre	14,702	8,168	Semi-bituminous coking coal.
Bois du Luc	14,358	7,977	" " "
La Louvière	15,127	8,404	" " "
Bracquegnies	15,363	8,535	" " "
Mariemont	15,168	8,427	" " "
Bascoup	14,911	8,284	Bituminous hard coal.
Sars-Longchamps	14,895	8,275	" " "
Houssu	14,945	8,303	" " "
Bassin de Charleroi.			
St. Martin, Fosse No. 3	14,954	8,308	Semi-bituminous coking.
Trieukaisin	15,069	8,372	" "
Poirier, Fosse St. Louie	14,421	8,012	" "
Bayemont, Fosse St. Charles	13,806	7,670	" hard coal.
Sacré-Madame	15,204	8,447	" "
Sars-les-Moulins, Fosse No. 7	15,125	8,403	" "
Carabinier-française No. 2	14,911	8,284	" "
Roton, veine Greffier	14,311	7,951	" "
Pont-du-Loup	14,947	8,304	" "
AUSTRIA-HUNGARY.			
Lower Austria.			
Grünbach	11,458	6,366	Semi-bituminous coal.
Thallern	7,057	3,921	Lignite or brown coal.
Upper Austria.			
Wolfsegg-Trannthal	6,006	3,337	Lignite or brown coal.

TABLE I. — *Continued.*

Coals, Locality of Beds.	B.T.U.	Calories.	Nature.
Styria.			
Leoben	9,666	5,370	Lignite or brown coal.
Fohnsdorf	9,187	5,104	" " "
Göriach	6,222	3,457	" " "
Köflach	6,867	3,815	" " "
Wies	7,997	4,443	" " "
Trifail	7,556	4,198	" " "
Bohemia.			
Kladno	10,675	5,931	Semi-bituminous coal.
Buschtehrad	8,865	4,925	" "
Libuschin	9,900	5,500	" "
Schlan	7,979	4,433	" "
Rakonitz-Lubna	7,257	4,032	" "
Pilsen	9,318	5,177	" "
Schatzlar	9,552	5,307	" "
Aussig	6,408	3,560	Lignite or brown coal.
Dux	7,808	4,338	" " "
Bilin	8,182	4,546	" " "
Brux	8,274	4,597	" " "
Moravia.			
Rossitz	12,533	6,974	
M. Ostram	12,623	7,013	
Gaya	4,858	2,699	Lignite or brown coal.
Goding	5,056	2,809	" " "
Silesia.			
P. Ostran	12,564	6,980	Bituminous coal.
Orlan-Lazy	12,389	6,883	" "
Poremba	11,057	6,143	" "
Karwin	13,021	7,234	" "
Taklowetz	11,932	6,632	" "
Hungary.			
Fünfkirchen	10,276	5,709	Cannel coal.
Anina	11,356	6,309	Cannel coal.
Neufeld	5,200	2,889	Lignite or brown coal.
Brennberg	8,325	4,625	" " "
Aika	6,913	3,841	" " "
Salgo-Tarjan	7,966	4,426	" " "
Dorog-Annathal	7,709	4,283	" " "
Tokod	8,069	4,483	" " "
Dalmatia.			
Siveric	8,087	4,493	Lignite or brown coal.
Istria.			
Arsa	10,182	5,657	Lignite or brown coal.
Transylvania.			
Petrozsény	11,286	6,270	
Egeres	8,692	4,829	Lignite or brown coal.
Bosnia.			
Zenica	7,911	4,359	Lignite or brown coal.

AUSTRALIA.

Composition of Australian Coals.

Specific gravity	1.312	
Coke	68.0	per cent
Volatile matter	31.7	"
Sulphur	0.5	"
Ash	8.3	"

Australian coal is jet-black and brilliant, very brittle, and breaks with a cubical fracture like Newcastle coal. It is bituminous and cokes like Newcastle coal.

JAPAN.

Japanese coal is slightly more bituminous than Welsh coal.

SOUTH AFRICA.

The principal coal mining areas in the Transvaal are situated at Boksburg, Brakpan Springs, Heidelberg, Vereeniging, and Middleburg, all these being on the Stormberg Bed of the Karoo Formation. Of these the Middleburg coal is generally considered the best.

In Cape Colony the Indwe, Molteno, Cyphergap and Sterkstroom Collieries are the best, but the coal from them necessitates the use of extra long and wide grates, and the frequent cleaning of the fires.

The coal from the Cyphergap Colliery is dirty with some 31 per cent of refuse, and has less than 60 per cent of the calorific value of good English coal.

The coal from the Indwe Colliery has the following analysis:

Specific gravity	1.51	per cent
Moisture	1.44	"
Ash	3.13	"
Coke	79.42	"
Sulphur	.69	"
Non-combustible constituents	31.57	"
Combustible constituents	68.43	"
Fixed carbon	49.28	"
Volatile combustible constituent	19.14	"
Heat value	9,200	B.T.U.

In the Orange Colony coal is found at Kronstad and Parys.

In Natal the coal raised at Newcastle and Elandslaagte is of good quailty, as is that obtained in South Rhodesia, at Wankie.

Character of Coal.—The following table gives the approximate percentage of fixed carbon and volatile matter in the different kinds of coal:

TABLE II.—CHARACTER OF COAL.

Coal.	Fixed Carbon per cent of Combustible.	Volatile Matter per cent of Combustible.
Anthracite	100 to 92	0 to 8
Semi-anthracite	92 to 87	8 to 13
Semi-bituminous	87 to 75	13 to 25
Bituminous	75 to 50	25 to 50
Lignite	Below 50	Over 50

The theoretical heat value which a fuel develops when consumed under perfect conditions can only be attained in the laboratory, and in practice this result is only approximately reached. The unit in which this heat value is expressed is the British Heat Unit or thermal unit, which is used in Great Britain and the United States, and the Calorie, which is employed in the countries using the metric system. The British Thermal Unit is the amount of heat required to raise the temperature of a pound of water, at 39° Fahr., 1° Fahr. The abbreviation is B.T.U. The Calorie is the amount of heat required to raise the temperature of 1 kilogram of water 1° at 4° Centigrade, the abbreviation of which is C. To convert B.T.U. per pound to C. per kilogram divide by 3.968 and *vice versa.*

Analysis.—The elements in the coal which have a heat value are the carbon, both fixed and volatile, hydrogen and sulphur. Coal also contains some water, which, requiring heat for its evaporation, detracts proportionately from the thermal value of the fuel. For practical purposes the carbon and hydrogen alone should be taken into consideration in determining the heating value of the coal from its analysis; either the approximate or the ultimate analysis may be used, as may be available. In most cases, however, the approximate analysis alone can be obtained, as the ultimate analysis of coal is rather difficult and not often given.

For computing the heating value of coal in B.T.U., under theoretically perfect conditions, all pure carbon and hydrogen, with only the proper amount of oxygen added to make combustion complete, is usually calculated by the use of Dulong's formula:

$$B.T.U. = 145\,(C + 4.28\left(H - \frac{O}{8}\right) + 0.28\,S).$$

In this formula the elements are designated by the letters:

C = Carbon.
H = Hydrogen.
O = Oxygen.
S = Sulphur.

The above-mentioned method of determining the heat value of the coal is theoretical, the actual heat value as determined by laboratory experiment may vary from it 5 per cent to 10 per cent; much greater variation will be found if the attempt is made to determine the heating value by the amount of water evaporated under practical service conditions in the boiler, this last giving the lowest value of all. In the laboratory the heating value of the coal is determined by the use of the calorimeter, a number of forms of which have been devised. The simplest and most convenient is that of Mahler, which is a modification of the Berthelot. In this instrument combustion takes place in an atmosphere of oxygen gas inside of a metal bomb. This bomb is submerged in water of known weight. The sample of coal to be tested is finely powdered, weighed and suspended on a platinum plate in the center of the bomb, after which the cover is screwed on and oxygen pumped in through a valve at the top; a pressure of 20 to 25 atmospheres per square cm. (300 to 370 pounds to the square inch) being used to insure

a large excess of oxygen when combustion takes place. The bomb is then placed in water which is constantly stirred until the whole apparatus comes to the same temperature, and enough readings are taken from a thermometer to establish the rate of radiation under the conditions existing before combustion. It is well to have the water at the same temperature as the room, or slightly above it. When all is ready the coal sample is ignited by means of an electric current, passed through a fine iron wire, suspended from terminals inside the bomb, in such a way as to touch the coal. This wire fuses upon the passage of the current and ignites the coal, which, owing to the atmosphere of oxygen, burns rapidly and completely, giving up its heat to the walls of the bomb, from which it passes to the water. The rise in the temperature of the water is carefully noted, the observations being taken until the whole arrives at

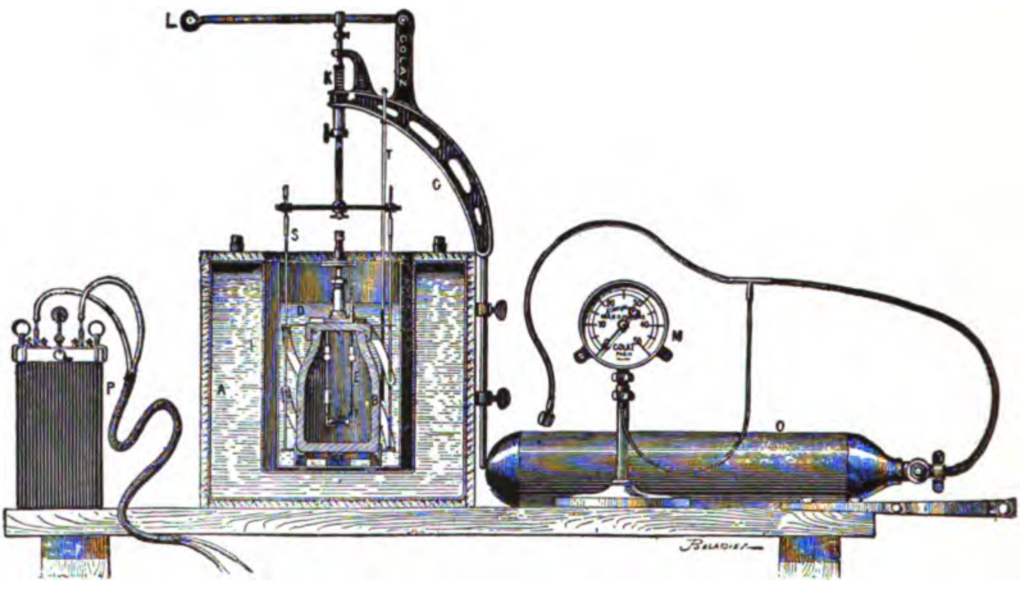


FIG. 1. Calorimeter of M. Pierre Mahler for Determining the Heating Value of Fuels.

EXPLANATION: A water jacket to diminish radiation. B — Steel bomb, lined with enamel. C — Platinum pan for coal. D — Calorimeter containing weighed water. E — Electrode. F — Fuse wire. G — Support for agitator and thermometer. K — Spring and screw for revolving agitator. L — Lever of agitator. M — Pressure gange. O — Oxygen cylinder. P — Electric battery. S — Agitator. T — Thermometer.

the same temperature and begins to cool, and the rate of cooling is established. The thermometer used is graded in fiftieths of a degree centigrade, and can be read to one-half of a 100th of a degree. In this way the loss through radiation during combustion may readily be determined and the proper allowance made. The combustion is always complete and no loss of heat occurs from escaping gases, because no gases escape until the operation is completed and the bomb opened. An illustration of this calorimeter is given in Fig. 1.

In a power plant it is of prime importance that the thermal value of the fuel should be known, because the whole efficiency of the plant is affected thereby. The coal, as

far as possible, should be purchased on the basis of the heat units contained, and when possible the contractor should be tied down to a standard value, a deduction being made for shipments which do not reach the guaranteed value, and a premium being paid for excess heat units.

The method of sampling the coal should be by taking a small portion from each filling of the weighing hopper. These samples should be quartered and mixed and a final sample should be obtained to represent the average value of the shipment. Where the size of the plant warrants it, the most practical method of sampling the coal is by means of an automatic sampling machine, such as is used in the large smelters and refineries throughout the world. The final sample is pulverized and tested for its heat value in the bomb calorimeter, after which approximate analysis is made of another portion of the sample. This method of purchasing coal has been successfully used for several years in large power plants.

In the boiler room it is desirable to keep account of the amount of coal burned in each boiler, and likewise of the firemen handling this coal, and it will frequently be found that an increase of economy can be secured by offering premiums for the smallest fuel consumption. These premiums offer an incentive to the fireman to study the conditions under which coal is burnt and thereby to increase his efficiency, contributing greatly to the reduction of the fuel bill. In continental Europe many firemen have to serve a certain apprenticeship at a training school for firemen, and such men have no difficulty in securing higher wages than untrained firemen.

COMBUSTION.

Combustion.—Combustion of carbon is a rapid chemical action, or union of carbon and oxygen forming carbon dioxide. The combustible elements in coal are carbon, hydrogen and sulphur; different coals contain from 70 per cent to 95 per cent of carbon (C), from 1 per cent to 10 per cent of hydrogen (H), from 0.4 per cent to 2 per cent of sulphur (S), from 1 per cent to 10 per cent of water (H_2O), and from $1\frac{1}{2}$ per cent to 18 per cent of ashes. The table, Fig. 1, given below gives the approximate analyses of the heating value of American coals.

Air Required. — The theoretical amount of air required to completely consume a pound of carbon, which may also be taken without great error for a pound of combustible, is 12 pounds; in practice, however, with natural draft from 25 to 30 pounds is required, while with artificial draft the amount of air may be decreased to 18 pounds, about 50 per cent more than the theoretical amount. The reason for the large increase where natural draft is used is that the ordinary chimney does not produce draft of intensity enough to penetrate the bed of the fire; to obtain the necessary air for complete combustion an excess must be supplied. This excess passes through the fire unconsumed, mingles with the gases of combustion, and to a certain extent cools them. With artificial draft a smaller grate and heavier fire is used, the air is forced through every portion of the coal, and complete chemical action

TABLE I.—PROXIMATE ANALYSES AND HEATING VALUES OF AMERICAN COALS.

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Heating Value per lb. coal, heat units.	Volatile Matter per cent of combustible.	Heating Value per lb. combustible, heat units.	Theoretical Evaporation lbs. water from and at 212° per lb. combustible
Anthracite.									
Northern coal field	3.42	4.38	83.27	8.20	.73	13,160	5.00	14,900	15.42
East Middle coal field	3.71	3.08	86.40	6.22	.58	13,420	3.44	14,900	15.42
West Middle coal field	3.16	3.72	81.59	10.65	.50	12,840	4.36	14,900	15.42
Southern coal field	3.09	4.28	83.81	8.18	.64	13,220	4.85	14,900	15.42
Anthracite from one mine.									
Egg . . . . . Screen 2½″–1¾″	....	....	88.49	5.66	....	....	....	....	....
Stove . . . . Screen 1¾″–1¼″	....	....	83.67	10.17	....	....	....	....	....
Chestnut . . . Screen 1¼″– ¾″	....	....	80.72	12.67	....	....	....	....	....
Pea . . . . . Screen ¾″– ½″	....	....	79.05	14.66	....	....	....	....	....
Buckwheat . . Screen ½″– ¼″	....	....	76.92	16.62	....	....	....	....	....
Semi-Anthracite.									
Loyalsock field	1.30	8.10	83.34	6.23	1.63	13,920	8.86	15,500	16.05
Bernice basin	.65	9.40	83.69	5.34	.91	13,700	10.98	15,500	16.05
Semi-Bituminous.									
Broad Top, Pa.	.79	15.61	77.30	5.40	.90	14,820	17.60	15,800	16.36
Clearfield County, Pa.	.76	22.52	71.82	3.99	.91	14,950	24.60	15,700	16.25
Cambria County, Pa.	.94	19.20	71.12	7.04	1.70	14,450	22.71	15,700	16.25
Somerset County, Pa.	1.58	16.42	71.51	8.62	1.87	14,200	20.37	15,800	16.36
Cumberland, Md.	1.09	17.30	73.12	7.75	.74	14,400	19.79	15,800	16.36
Pocahontas, Va.	1.00	21.00	74.39	3.03	.58	15,070	22.50	15,700	16.25
New River, W.Va.	.85	17.88	77.64	3.36	.27	15,220	18.95	15,800	16.36
Bituminous.									
Connellsville, Pa.	1.26	30.12	59.61	8.23	.78	14,050	34.03	15,300	15.84
Youghiogheny, Pa.	1.03	36.50	59.05	2.61	.81	14,450	38.73	15,000	15.53
Pittsburg, Pa.	1.37	35.90	52.21	8.02	1.80	13,410	41.61	14,800	15.32
Jefferson County, Pa.	1.21	32.53	60.99	4.27	1.00	14,370	35.47	15,200	15.74
Middle Kittanning seam, Pa.	1.81	35.33	53.70	7.18	1.98	13,200	40.27	14,500	15.01
Upper Freeport seam, Pa. and O.	1.93	35.90	50.19	9.10	2.89	13,170	43.59	14,800	15.32
Thacker, W.Va.	1.38	35.04	56.03	6.27	1.28	14,040	39.33	15,200	15.74
Jackson County, O.	3.83	32.07	57.60	6.50	....	13,090	35.76	14,600	15.11
Brier Hill, O.	4.80	34.60	56.30	4.30	....	13,010	38.20	14,300	14.80
Hocking Valley, O.	6.59	34.97	48.85	8.00	1.59	12,130	42.81	14,200	14.70
Vanderpool, Ky.	4.00	34.10	54.60	7.30	....	12,770	38.50	14,400	14.91
Muhlenberg County, Ky	4.33	33.65	55.50	4.95	1.57	13,060	38.86	14,400(?)	14.91
Scott County, Tenn.	1.26	35.76	53.14	8.02	1.80	13,700	34.17	15,100(?)	15.63
Jefferson County, Ala.	1.55	34.44	59.77	2.62	1.42	13,770	37.63	14,400(?)	14.91
Big Muddy, Ill.	7.50	30.70	53.80	8.00	....	12,420	36.30	14,700	15.22
Mt. Olive, Ill.	11.00	35.65	37.10	13.00	....	10,490	47.00	13,800	14.29
Streator, Ill.	12.00	33.30	40.70	14.00	....	10,580	45.00	14,300	14.80
Missouri	6.44	37.57	47.94	8.05	....	12,230	43.94	14,300(?)	14.80
Lignites and Lignitic Coals.									
Iowa	8.45	37.09	35.60	18.86	....	8,720	51.03	12,000(?)	12.42
Wyoming	8.19	38.72	41.83	11.26	....	10,390	48.07	12,900(?)	13.35
Utah	9.29	41.97	44.37	3.20	1.18	11,030	48.60	12,600(?)	13.04
Oregon Lignite	15.25	42.98	33.32	7.11	1.66	8,540	54.95	11,000(?)	11.39

By courtesy of the Babcock & Wilcox Co.

takes place, the oxygen being more fully consumed. In other words, in the latter case the force is more concentrated than in the former and the work performed more effectively. The greater the percentage of carbon dioxide (CO_2) contained in the

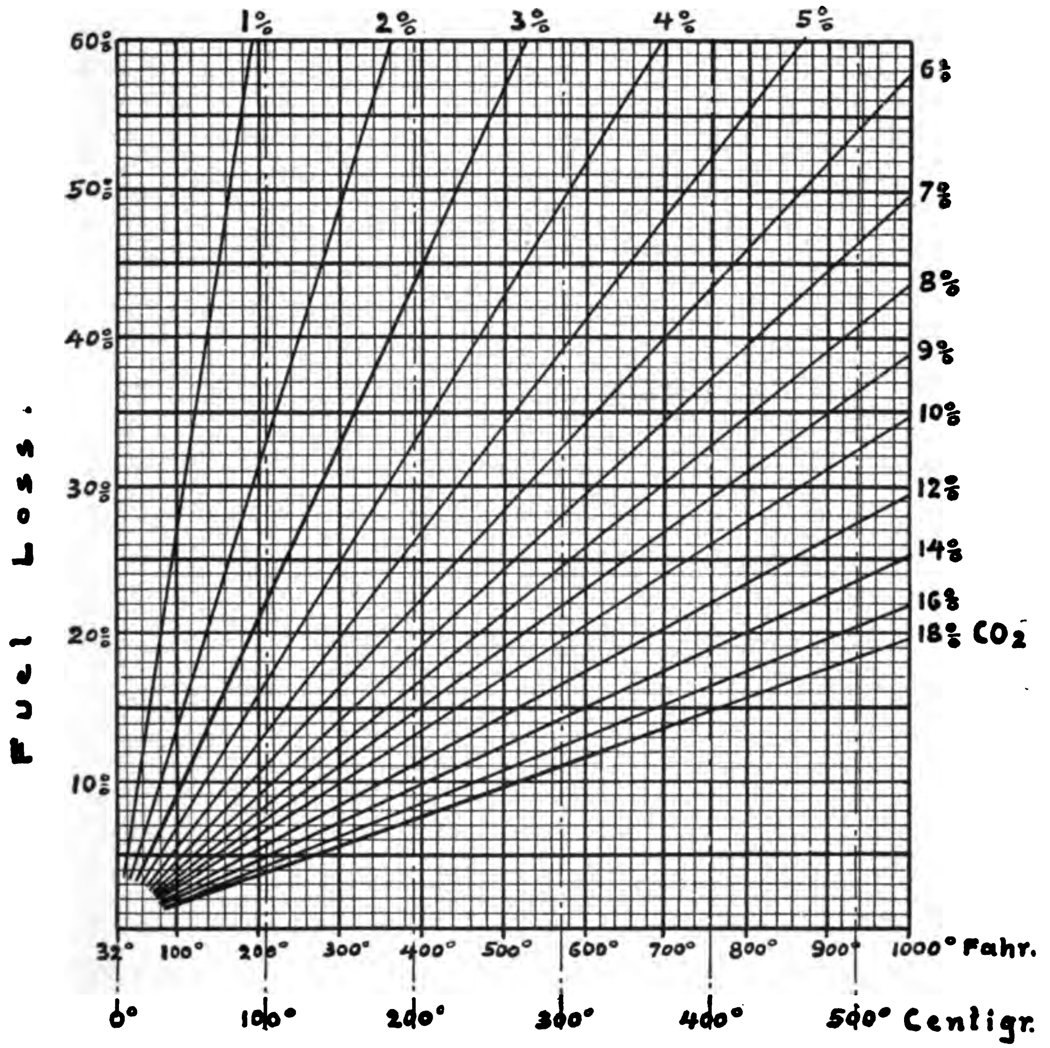


FIG. 2. Fuel Loss in Flue Gases.

flue gas the greater the efficiency. A chart shown in Fig. 2 gives the percentage of carbon dioxide for various chimney temperatures, and the resultant percentage of fuel loss is indicated at the left-hand side of the chart. The diagonal lines show the percentage of carbon dioxide, and chimney temperatures are given at the bottom in Fahrenheit and centigrade degrees.

CO_2 Recorder. — A valuable instrument for a power plant, which is at present much in use, is the CO_2 or gas composimeter, which enables a record to be kept of

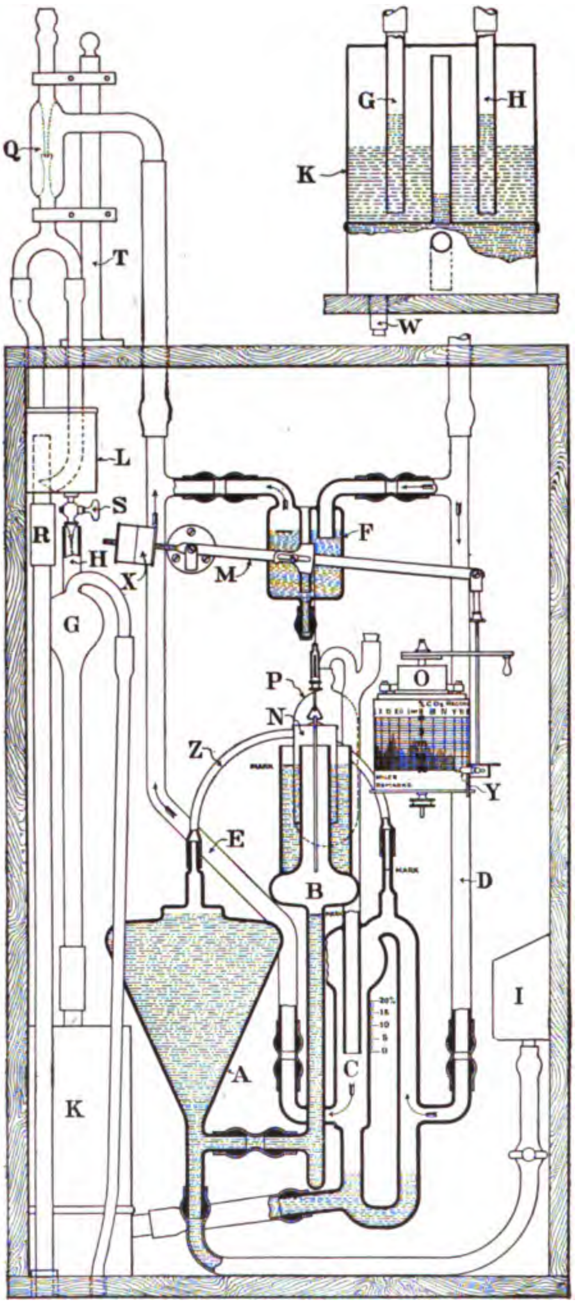


FIG. 3. Ados (Sarco) CO_2 Recorder, Water Motor Type.

the percentage of carbon dioxide in the chimney gases. It may be advantageous to the fireman to arrange this apparatus so that he can observe the movements of the needle and govern his fire accordingly; it being generally found that a fireman can be taught to read this instrument with but a slight amount of instruction. There are several different instruments on the market for this purpose, such as the

Arndt Econometer.
Custodis Gas Balance.
Uehling Gas Compometer.
Ados or Sarco Carbon Dioxide Recorder.
Simmance & Abadil CO_2 Recorder.

The Arndt apparatus is used when a complete analysis of the gas is to be made. The Uehling and the Ados apparatus give a continuous record on a strip of paper, as does also the Simmance & Abadil, while the other instruments are not so arranged, being more suited for laboratory work. The Ados (Sarco) apparatus is shown in Fig. 3.

These recorders are frequently used in power plants and give satisfactory service. The operation of the instrument is as follows:

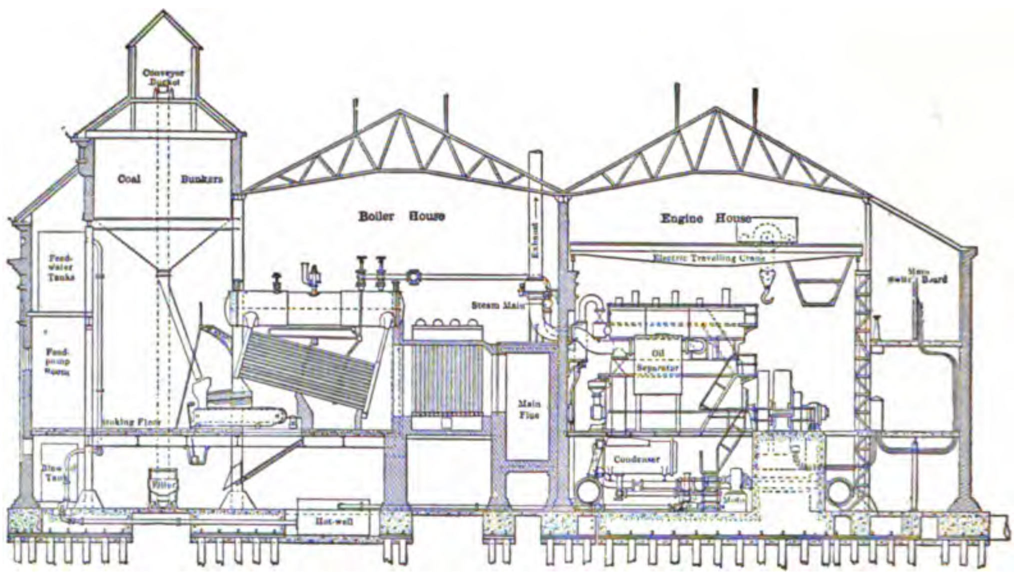
A $\frac{3}{4}$-inch pipe, which taps the side flue or last combustion chamber of each boiler, is connected to the inlet pipe D of the instrument and the gas is drawn through the machine by an aspirator Q, fixed to the top of the instrument by means of standard T.

The power required to procure and deal with the gas samples is derived from a

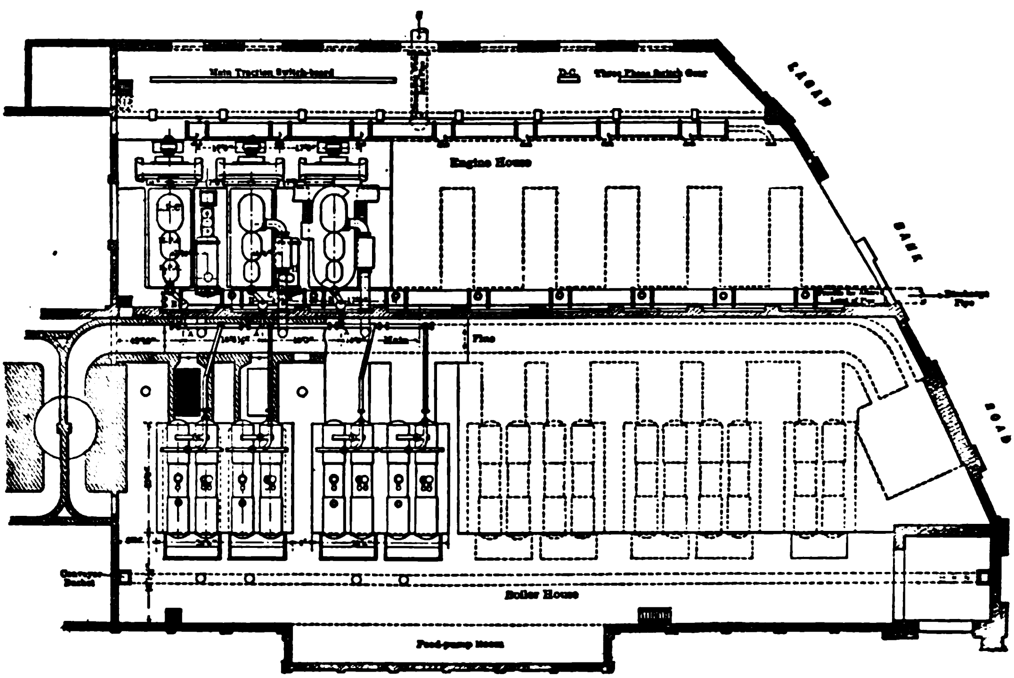
fine stream of water at a head of about 2 to 3 feet; 6 to 8 gallons are required per hour (according to the speed at which the machine is operated). After actuating ejector Q, a portion of the water flows to the small tank L, which serves as a pressure regulator, and is provided with an overflow tube R. From this tank the water enters tube H in a fine stream, the strength of which is adjusted by the cock S (according to the number of records that may be desired per hour), and gradually fills the vessel K. Vessel K consists of an upper and a lower compartment, the two being in communication with one another through a tube erected in the upper chamber and reaching nearly to the top of same. The water, which enters this vessel K through the tube H, gradually fills the upper chamber and thus compresses the air contained in it. This pressure is transmitted to the lower compartment through the communication tube above mentioned, and here acts upon the mixture of glycerine and water (1 part of the former to 3 of the latter) with which this is filled, driving it out into the calibrated tube C. While this has been taking place the aspirator Q has been drawing a continuous stream of gas right through D, C and E in the direction indicated by the arrows. When the rising liquid in C has reached the inlet and outlet to this vessel, no further gas can enter the calibrated tubes for the moment, and the aspirator will now draw the gas through the seal F, and out in the direction of the arrow for the time being. Before the liquid can close the center tube in C, the gas has to overcome the slight resistance offered by the elastic bag P, and is thereby forced to assume atmospheric pressure. The moment the liquid has sealed the lower open end of this center tube, exactly 100 cub. cm. of flue gas are trapped off in the outer vessel C and its companion tube, under atmospheric pressure. As the liquid rises farther, the gas is forced through the thin tube Z and into vessel A, which is filled with a solution of caustic potash at 1.27 specific gravity. Upon coming into contact with the surface of the potash and the moistened sides of the vessel, the gas is freed from any carbon dioxide that may be contained in the sample, this being rapidly and completely absorbed by the potash. The remaining gas gradually displaces the potash solution in A, sending it up into vessel B. This has an outer jacket, filled with glycerine and supporting a float N. Through the center of this float reaches a thin tube, through which the air in B is kept at atmospheric pressure. The float is suspended from the pen gear M by a silk cord and counterbalanced by the weights X. The rising liquid in B first forces a portion of the air therein out through the center tube in the float, and then raises the latter. This causes the pen lever to swing upwards, carrying pen Y with it.

The mechanism is so calibrated and adjusted that the pen will travel right to the top, or zero line on the chart when only atmospheric air is passing through the machine and nothing is absorbed by the potash in A.

Thus, should any carbon dioxide be contained in the gas sample, it would be absorbed by the potash in A, not so much of this liquid would be forced up into vessel B and the float would not cause the pen to travel up so high on the chart, in exact accordance with the amount of CO_2 absorbed. The tops of the vertical lines recorded on the chart, therefore, provide a continuous curve showing the percentage of CO_2 contained in the exit gases from the flues, on a permanent diagram arranged for twenty-four hours.



GENERAL CROSS SECTION



Extension of Municipal Light and Power Plant at Belfast, Ireland.

When the liquid in C has reached the mark on the narrow neck of that tube, the whole of the 100 cub. cm. have been forced on to the surface of the potash, one analysis being thus complete. At this moment the power water, which simultaneously with rising in tube H has also traveled upwards in siphon G, will have reached the top of this siphon, which then commences to flow.

Through siphon G a much larger quantity of water is disposed of than flows in through cock S, so that the power vessel K is rapidly emptied again.

The moment the pressure on this vessel is released, the liquid from C returns into the lower compartment, and float N to its original position.

As soon as the liquid in C has fallen below the gas-inlet and gas-outlet to this vessel, the whole of the remaining gas is rapidly sucked out through E by the ejector Q.

DRAFT.

Meaning. — The word "draft" has a double meaning, and as a result there is some confusion; in regard to combustion it only refers to the difference in air-pressure between the ash pit and the furnace chamber, while, when considered on a broader basis, it refers to the total intensity of the draft or difference in pressure existing between the external air and the interior of the boiler setting. This intensity may be measured at a number of points, therefore, unless the position of the draft gauge is specified, the value of any tables referring to this subject are greatly reduced. The boiler maker is very careful in his guarantee to specify the draft required at the boiler outlet, and the stoker manufacturer requires a certain draft intensity at the bridge wall, the chimney builder will specify the draft generated with flue gases of a certain temperature when the barometer is normal, and may require other conditional qualifications; the builder of fans will guarantee the pressure at the fan outlet for forced draft and the vacuum at the fan inlet for induced draft. From this it will be seen that the designer of the power plant has the difficult problem of so arranging the necessary flues and conduits that a harmonious result is secured at the lowest first cost and expense of maintenance. Each case must be judged entirely on its own merits and requires considerable knowledge of what has been done, and what is feasible on the part of the man responsible for the results, for a decision must be made at a very early stage in the design of the plant in regard to the method to be used; an error of judgment in this regard will, if the draft is insufficient, necessitate expensive changes and alterations after the plant is in operation, and the installation of any artificial draft-apparatus at this time will be greatly hampered in design by the existing structure, and therefore undesirable in many ways. In some cases it will be found that the draft intensity provided is too great, and while this is a fault insomuch as it shows that a greater investment has been made than the case justified, it is better to err on this side, but care must be used in order that too great an error is not made. The prevailing complaint in most plants is "lack of draft," and a large number of devices have been invented and put in use for supplying the deficiency.

Draft is either measured in inches or ounces. The following Table I, gives the corresponding pressures in inches and ounces:

TABLE I.

1/32 inch	=	.018 ounce	5/8 inch	=	.363 ounce
1/16 "	=	.036 "	3/4 "	=	.436 "
1/8 "	=	.072 "	7/8 "	=	.508 "
3/16 "	=	.109 "	1 "	=	.581 "
1/4 "	=	.145 "	1 1/4 inches	=	.726 "
5/16 "	=	.181 "	1 1/2 "	=	.872 "
3/8 "	=	.218 "	1 3/4 "	=	1.017 "
1/2 "	=	.290 "	2 "	=	1.162 "

Production. — There are several methods of producing draft: the chimney, fans for forced or induced draft, and steam jet blowers in a variety of applications.

The chimney is the oldest method of producing draft and acts by the difference in weight between the column of hot gases in the shaft, and that of an equal column of atmospheric air; a reduced pressure is produced at the base of the stack, in the flues and boiler-setting, allowing air to flow in through the burning coal on the grate from the heavier external atmosphere.

Induced draft is similar to chimney draft, except that a fan or other means is used to produce the draft.

Forced draft may be on either of two systems, the closed fire room which is generally found on the ships, and the closed ash-pit system which is usually found in power plants. In either case the air under pressure is admitted to the lower side of the grate and passes through the fire.

Loss. —The average loss of draft in a water-tube boiler between the furnace and the flue outlet at the boiler wall is 0.20 inch of water approximately; the data refers to the regular Babcock & Wilcox or Stirling boiler. This loss varies according to the design of boiler used and the method of forcing, but a common allowance to cover this loss is 0.25 to 0.50 inch of water, the latter when the boilers are forced, and the balance of the draft specified by the boiler maker is required to pass the air through the grate and fire. One prominent builder of water-tube boilers calls for from 0.50 to 0.70 inch of water at the boiler flue outlet, with semi-bituminous coal and boilers operated at their normal capacity, and a larger draft pressure is required should the boilers be forced. The kind of fuel to be burned must also be considered; for instance, the small sizes of anthracite coal require a high draft intensity, and with stokers, for the same kind of coal, it will require a greater intensity of draft to burn the same quantity of coal per square foot of grate than is required for hand firing.

The design of the smoke flues or boiler breechings has a considerable influence on the draft intensity available, and there is comparatively little accurate data on the

subject. Square flues are not as efficient as circular flues, but the exigencies of construction usually require the adoption of rectangular flues. The losses in flues are due to the friction and leakage. Right-angled bends are productive of considerable loss of draft. A convenient "rule of thumb" allows 0.15 inch draft loss per hundred feet of flue and 0.075 inch for each bend when circular flues are used; these values are doubled for brick lined flues of rectangular section. The above, of course, only applies when sufficient flue area is provided.

Economizers cause a considerable loss in draft (often as high as 0.4 to 0.5 of an inch), and it is usually necessary to increase the height of the chimney 25 per cent.

The unbalanced pressure due to the difference in weight between the hot column of gas in a chimney and the external air is partially absorbed by the inertia of the air, or its resistance to being set in motion, and the friction in the chimney; additional losses may be caused by the lack of proper baffle walls. In addition the chimney must be designed to supply a draft of sufficient intensity to overcome the combined resistance of the boiler, grate, flues and dampers, and it must be able to supply the maximum draft requirements under the most unfavorable conditions of the barometer and atmospheric humidity. The quantity of coal which can be burned on a grate depends upon the quantity of air which can be forced through the grate. As will be shown in the chapter on combustion, the latter value may range from the theoretical amount of air required to 50 per cent or more in excess.

Chimney Draft. — The following Table II, gives the height of water column in inches, due to the unbalanced pressure in a chimney 100 feet high for various temperatures of the external air and hot gases. As the draft intensity varies directly with the height of the chimney, the intensity of draft due to higher or lower chimney can be found by proportion.

TABLE II. — HEIGHT OF WATER COLUMN DUE TO UNBALANCED PRESSURES IN CHIMNEY 100 FEET HIGH.*

Temperature in Chimney.	Temperature of External Air. Barometer 14.7 Lbs. per Square Inch.										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200°	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
220°	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
240°	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
260°	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
280°	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
300°	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
320°	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
340°	.662	.638	.593	.563	.530	.501	.472	.443	.419	.392	.367
360°	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
380°	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
400°	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
420°	.753	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
440°	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
460°	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
480°	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
500°	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

* "The Locomotive," 1884.

The foregoing table emphasizes the value of high chimney temperatures in producing draft, and clearly shows the reason why chimneys act better in cold weather. In practice it will be found that the actual draft intensity produced is lower than the computed intensity, owing to the fact that friction must be overcome and the heat of the gases decreases as they approach the top of the chimney.

The formula used in computing this table is:

$$F = .192\ H\ (D - d)$$

in which

F = Intensity of draft in inches of water.
H = Height of chimney in feet.
D = Density of external air.
d = Density of hot gases.
.192 = A factor for converting pressure in lb. per square foot to inches of water.

The theoretical velocity of the gases due to this draft intensity can be computed by the following formula:

$$v = \frac{2g \times 800h}{12}$$

in which

v = The theoretical velocity in feet per second.
g = Gravity (32.2).
h = Head in inches of water.
800 = The ratio between the weight of equally high columns of water and the flue gases at the temperature of $+ 32^\circ$ F.

In using this formula for theoretical accuracy a correction factor is necessary to cover the temperature of the flue gases, but owing to the great number of unknown factors in the problem as it exists at any power plant, such fine drawn assumptions are beside the mark, and the formula can be used as it stands.

Kent's formula for the area of a chimney is:

$$A = \frac{0.06 \times W}{\sqrt{H}}$$

in which

A = Area of chimney in square feet.
W = Total fuel consumption in pounds per hour.
H = Height of chimney in feet.

The following Table III from Kent's Pocket Book gives the size of chimney based on a fuel consumption of five pounds of coal per horse-power hour, based on the commercial horse-power of the boilers, and a similar one, Table IV, is given, based on four pounds of coal per horse-power hour from Christie on "Chimney Design."

TABLE III.—KENT'S TABLE OF SIZE OF CHIMNEYS FOR STEAM BOILERS.

Formula: H.P. = $3.33(A - 0.6\sqrt{A})\sqrt{H}$. (Assuming 1 H.P. = 5 lbs. of coal burned per hour.)

Diameter, Inches.	Area A. Sq. feet.	Effective Area, $E = A - 0.6\sqrt{A}$. Sq. feet.	HEIGHT OF CHIMNEY.														Equivalent Square Chimney. Side of Square, $\sqrt{E} + 4$ in.
			50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′	
			COMMERCIAL HORSE-POWER OF BOILER.														
18	1.77	.97	23	25	27	29	...	...	...	...	...	...	...	...	...	...	16
21	2.41	1.47	35	38	41	44	...	...	...	...	...	...	...	...	...	...	19
24	3.14	2.08	49	54	58	62	66	...	...	...	...	...	...	...	...	...	22
27	3.98	2.78	65	72	78	83	88	...	...	...	...	...	...	...	...	...	24
30	4.91	3.58	84	92	100	107	113	119	...	...	...	...	...	...	...	...	27
33	5.94	4.48	...	115	125	133	141	149	156	...	...	...	...	...	...	...	30
36	7.07	5.47	...	141	152	163	173	182	191	204	...	...	...	...	...	...	32
39	8.30	6.57	...	...	183	196	208	219	229	245	268	...	...	...	...	...	35
42	9.62	7.76	...	...	216	231	245	258	271	289	316	342	...	...	...	...	38
48	12.57	10.44	...	...	...	311	330	348	365	389	426	460	492	...	...	...	43
54	15.90	13.51	...	...	...	...	427	449	472	503	551	595	636	675	...	...	48
60	19.64	16.98	...	...	...	...	536	565	593	632	692	748	800	848	894	...	54
66	23.76	20.83	...	...	...	...	...	694	728	776	849	918	981	1040	1097	1201	59
72	28.27	25.08	...	...	...	...	...	835	876	934	1023	1105	1181	1253	1320	1447	64
78	33.18	29.73	...	...	...	...	...	...	1038	1107	1212	1310	1400	1485	1565	1715	70
84	38.48	34.76	...	...	...	...	...	...	1214	1294	1418	1531	1637	1736	1830	2005	75
90	44.18	40.19	...	...	...	...	...	...	...	1496	1639	1770	1893	2008	2116	2318	80
96	50.27	46.01	...	...	...	...	...	...	...	1712	1876	2027	2167	2298	2423	2654	86
102	56.75	52.23	...	...	...	...	...	...	...	1944	2130	2300	2459	2609	2750	3012	91
108	63.62	58.83	...	...	...	...	...	...	...	2090	2399	2592	2771	2939	3098	3393	96
114	70.88	65.83	...	...	...	...	...	...	...	...	2685	2900	3100	3288	3466	3797	101
120	78.54	73.22	...	...	...	...	...	...	...	...	2986	3226	3448	3657	3855	4223	107
132	95.03	89.18	...	...	...	...	...	...	...	...	3637	3929	4200	4455	4696	5144	117
144	113.10	106.72	...	...	...	...	...	...	...	...	4352	4701	5026	5331	5618	6155	128

For pounds of coal burned per hour for any given size of chimney, multiply the figures in the table by 5.

The capacity of the chimney for other rates of fuel consumption is easily found from these tables by proportion, as, for example, in Table III, where a coal consumption of 5 pounds per boiler horse-power per hour has been assumed; the figures given in this table may be multiplied by the ratio of 5 to the maximum expected coal consumption per horse-power hour. Thus, with conditions which make the maximum coal consumption only 2.5 pounds, the chimney 300 feet high by 12 feet diameter should be sufficient, for 6,155 × 2 = 12,310 horse-power.

A table showing the practice of several prominent plants in actual operation, and a sufficient amount of data in regard to their equipment to enable comparisons to be made, is given in Table V.

TABLE IV. — CHRISTY'S TABLE OF SIZE OF CHIMNEYS FOR STEAM BOILERS.

Formula: H.P. = $3.25\ A\sqrt{H}$. (Assuming 1 H.P. = 4 lbs. of coal burned per hour.)

Diameter in Inches.	Area (A) Sq. feet.	HEIGHT OF CHIMNEY.														Equivalent Side of Square Chimney in Inches.
		50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′	
		COMMERCIAL HORSE-POWER OF BOILER.														
18	1.77	42	46	49	52	....	....	....	....	....	....	....	....	....	....	16
21	2.41	55	62	65	68	....	....	....	....	....	....	....	....	....	....	19
24	3.14	72	78	85	91	98	....	....	....	....	....	....	....	....	....	22
27	3.98	91	101	107	114	124	....	....	....	....	....	....	....	....	....	24
30	4.91	114	124	133	143	153	159	....	....	....	....	....	....	....	....	27
33	5.94	....	149	163	172	182	192	202	....	....	....	....	....	....	....	30
36	7.07	....	179	192	205	218	228	241	257	....	....	....	....	....	....	32
39	8.30	....	....	224	241	257	270	283	302	....	....	....	....	....	....	35
42	9.62	....	....	263	282	296	312	332	351	390	....	....	....	....	....	38
48	12.57	....	....	....	364	387	410	429	458	510	....	....	....	....	....	43
54	15.90	....	....	....	....	491	517	543	579	647	683	....	....	....	....	48
60	19.64	....	....	....	....	605	637	669	715	797	845	....	....	....	....	54
66	23.76	....	....	....	....	....	774	809	865	965	1021	1092	....	....	....	59
72	28.27	....	....	....	....	....	920	962	1051	1147	1215	1300	1378	....	....	64
78	33.18	....	....	....	....	....	....	1131	1206	1349	1459	1524	1619	1706	....	70
84	38.48	....	....	....	....	....	....	1310	1401	1563	1654	1768	1875	1976	2165	75
90	44.18	....	....	....	....	....	....	....	1609	1794	1898	2031	2155	2269	2486	80
96	50.27	....	....	....	....	....	....	....	1830	2041	2161	2311	2451	2584	2831	86
102	56.75	....	....	....	....	....	....	....	2067	2304	2434	2607	2766	2915	3195	91
108	63.62	....	....	....	....	....	....	....	2314	2584	2734	2935	3101	3269	3578	96
114	70.88	....	....	....	....	....	....	....	....	2879	3045	3257	3455	3643	3991	101
120	78.54	....	....	....	....	....	....	....	....	3191	3374	3611	3821	4037	4420	107
132	95.03	....	....	....	....	....	....	....	....	3861	4082	4368	4631	4882	5350	117
144	113.10	....	....	....	....	....	....	....	....	4596	4859	5200	5515	5811	6367	128

TABLE V. — CHIMNEY DATA OF RECENT POWER PLANTS.

	Waterside II, New York.	L Street, Boston.	Fisk Street, Chicago.	Port Morris, Yonkers, New York.	Chelsea, London.	Twin Municipal, Vienna.	Potomac, Wash., D. C.	59th Street, New York.
Height of chimney above grate in feet . . .	300*	232	205	250	253*†	205	185	225 †
Diameter at top in feet	20	16	18	15.5	19	12.5	12	15
Size of boiler in square feet	6500	5120	5000	6250	5210	3210	6040	6060
Number of boilers	24	16	16	12	20	10	8	12
Total grate surface per chimney in square feet	3024	1760	1600	1344	1660	876	880	1200
Ratio of chimney to grate	1:9.63	1:8.04	1:6.3	1:7.15	1:5.89	1:7.18	1:7.78	1:6.25

* Above lower grates. † Economizer.

The practice of proportioning a chimney according to the nominal horse-power of the boiler is peculiar to the United States alone; in Europe a more scientific analysis of the problem is used, but it is doubtful if the results attained are any more satisfactory than the more simple method used in America, owing to the large number of unknown quantities involved, and it is extremely doubtful whether the subject will ever be covered by a simple rational formula.

The efficiency of the chimney considered as a machine for the production of draft is low. The movement of the air depends upon the heating of the air, but its actual movement must be considered entirely upon mechanical principles, and the heat carried off by the escaping gases is absolutely wasted, so far as its utilization for any other purpose is concerned; that is, any attempt to extract heat from the gases leaving the boiler will result in a reduction of the draft. This loss is, therefore, always chargeable to the use of a chimney for the production of draft. The following Table VI, taken from "A Treatise on Mechanical Draft," issued by the B. F. Sturtevant Co. of Boston, Mass., shows the number of heat units carried off by escaping gases at different increases of temperature above that of the atmosphere, and varying excess of air supply over that theoretically required for complete combustion. It will be noted that these losses are of considerable magnitude. With coal having a thermal value of 11,720 B.T.U. per pound and an air supply 100 per cent in excess of the theoretical requirement, the percentage of heat lost will vary from 11.4 per cent with the escaping gases at 300° Fahr. above that of the atmosphere to 20.9 per cent when the difference in temperature is 500° Fahr.

TABLE VI. — SHOWING B.T.U. CARRIED OFF BY ESCAPING GASES AT VARIOUS TEMPERATURES ABOVE THAT OF THE ATMOSPHERE AND VARIOUS EXCESS AIR SUPPLY.

Excess of Air in per cent.	Temperature of Waste Gases above that of Atmosphere.					
	300°	350°	400° B.T.U.	450°	500°	550°
0	695	812	928	1,044	1,160	1,276
50	1,016	1,185	1,354	1,524	1,693	1,862
75	1,176	1,372	1,568	1,764	1,959	2,155
100	1,336	1,558	1,781	2,003	2,226	2,448
125	1,495	1,745	1,994	2,243	2,492	2,742
150	1,655	1,931	2,207	2,483	2,759	3,035
175	1,815	2,118	2,420	2,715	3,025	3,328
200	1,975	2,304	2,633	2,975	3,291	3,621

The efficiency of the chimney can be determined by the computation of the number of foot pounds required to produce the movement of the air or gases as compared with the foot pounds represented by the amount of heat expended in producing that movement. For example, assuming a chimney 100 feet high having an area of 10 square feet, the atmosphere at a temperature of +62° Fahr. and the chimney gases at +500° Fahr.

For the sake of simplicity it is assumed that no work is lost in friction and that heated air is substituted for the hot gases, their density and specific heat being approximately the same. Under these conditions the pressure difference at the base of the chimney will be found as follows:

$$p = h\ (d - d')$$

in which

p = the difference in pressure at base of chimney.
h = 100 feet = height of chimney in feet.
d = 0.0761 = the weight of one cubic foot of air at a temperature of + 62° Fahr.
d' = 0.0414 = the weight of one cubic foot of air at a temperature of + 500° Fahr.

Hence

$$p = 100\ (0.0761 - 0.0414) = 3.47 \text{ pounds per square foot.}$$

The height of the column of external air which will produce the above pressure per square foot is

$$H = h\left(\frac{d - d'}{d}\right).$$

Substituting the values in this formula and solving:

$$H = 100\left(\frac{0.0761 - 0.0414}{0.0761}\right) = 45.6 \text{ feet.}$$

The velocity of the air entering the chimney under this head will be:

$$v = \sqrt{2gH} = \sqrt{64.32 \times 45.6} = 54.2 \text{ feet per second.}$$

The weight of air moved per second will be:

$$\text{Weight} = 54.2 \times 0.0761 \times 10 = 41.25 \text{ pounds.}$$

In this computation 10 = the area of the chimney in square feet. The movement of this air is the result of heating it from +62° to +500°, that is through 500° — 62° = 438° Fahr. As the specific heat of air under a constant pressure is 0.237, the total heat expended per second in moving 41.25 pounds will be:

$$\text{Heat expended} = 41.25 \times 438 \times 0.237 = 4{,}291 \text{ B.T.U.}$$

As one heat unit is equivalent to 778 foot pounds, the energy equivalent of the above amount of heat is:

$$\text{Energy equivalent of heat} = 4{,}291 \times 778 = 3{,}338{,}398 \text{ foot pounds.}$$

The work actually done is the result of overcoming a pressure of 3.47 pounds per square foot over an area of 10 square feet, through a distance of 54.2 feet; that is,

$$\text{Actual work} = 3.47 \times 10 \times 54.2 = 1{,}881 \text{ foot pounds.}$$

And the efficiency of the chimney is:

$$\text{Efficiency} = \frac{1{,}881}{3{,}338{,}398} = 0.000563 = 0.0563 \text{ per cent.}$$

In actual practice the efficiency of the chimney is much lower than this figure, owing to the cooling of the gases, friction and other causes.

Mechanical Draft.— Mechanical draft may be either forced or induced; forced draft is created by forcing air under the grates, while induced draft is created by removing the gases of combustion, by a mechanical device, after they leave the boiler, thus producing a partial vacuum in the furnace and drawing air through the grates.

Mechanical draft, either forced or induced, possesses the advantage that it is under absolute control at all times, can be forced to any extent within reason, and is independent of atmospheric conditions which affect chimneys; forced draft being more in favor for large plants than the induced system. The disadvantage of mechanical draft is the liability to fail at critical moments. This can, in a way, be guarded against by duplicate installations, but such precautions are not infallible. The chimney, on the other hand, depends upon the ever-acting force of gravity, and so long as a fire can burn a certain amount of draft will be secured. The chimney, however, cannot be forced, it must be built large enough at the start, the draft can be reduced if excessive by dampers, but if not sufficient the only recourse is to reinforce it by mechanical methods.

Another great advantage in the use of mechanical draft is the low grade of coal that may be efficiently burned, and its adaptability to sudden calls for steam as required in power plants.

Regarding first cost, the blower installation may be much cheaper than natural draft; this depends, however, on the design of the plant, the operating expense of a blower when steam driven is about 1 per cent to 2 per cent of the total steam output. This, however, should not be considered, for the exhaust steam can be utilized, while the more economical combustion will outweigh this additional expense.

Forced Draft.— Forced draft on the closed ash pit is practically the only available method for use in power plants, as the closed fire-room system is out of the question, unless very expensive construction is adopted. With forced draft there is practically no limit to the amount of fuel which may be burned by forcing the system to its utmost, but such measures are not desirable for economical reasons. The fan is usually of sufficient size to supply a number of boilers. The air is drawn from the boiler room, thus assisting ventilation, and carried through ducts under the floor to each ash pit. The air ducts must be air-tight and with as few bends as possible, in order to reduce

leakage and friction. The total area of all branch outlets should be about 50 per cent larger than that of the main duct. The efflux of the air into the ash pit is controlled by suitable dampers or gates so arranged as to prevent ashes from falling into the openings. The common mistake of placing the air inlets on one side of the ash pits only results in intense local combustion on the grates at certain points, and a comparatively dead fire at others. It is better to introduce the air at the front and back as well as on the sides; better distribution can thus be insured. In many cases the above troubles are not discovered or realized until after the plant is in operation, and frequently this system is installed to help out insufficient chimney capacity. The bridge wall is usually not used for an inlet until the above-mentioned troubles have made themselves manifest.

The fan or blower capacity depends on the total quantity of fuel to be burned in all the grates, and an excess should be allowed to permit forcing the boilers. The air pressure depends upon the kind of fuel to be used and duct friction to be overcome; it is advisable to assume that the fan can deliver to the ash pits its full volume at 2 inches of water pressure, the fan should be able to deliver to the ducts at a pressure of 3.5 inches of water or two ounces per square inch, but this, of course, depends on the ducts and the general arrangement of the plant.

An advantage of forced draft over the induced draft system is that the air supplied by the fan is comparatively cool, and therefore the volume swept by the fan is smaller. The disadvantage arises from the complicated duct system required, and the power required to force the air through them; in many cases there is scant room to put in ducts, and highly undesirable expedients have to be adopted to get the installation in.

Induced Draft.— Induced draft is similar, as pertains to the main portion of the plant, to chimney draft, and fans or steam blowers may be used. Steam blowers or ejectors are used to reinforce chimney draft, being installed in the base of the stack. Such blowers are only suited to small chimneys, as previously mentioned, and are not economical. Induced draft fans are used in many cases with success, the chimney being reduced to a stub of only sufficient height to reject the hot gases and smoke clear of the buildings. The height of the stack is governed, for induced draft, by the demand for operating the plant so that it will not be a nuisance to the neighborhood, the actual requirements in this line being merely a discharge from the fan. A duplicate fan is installed in order to insure continuity of operation, but such precautions are seldom found necessary. Induced draft plants are usually employed in connection with economizers; this cools the gases somewhat, but at the same time there is considerable air leakage in the boiler and economizer settings, which are usually built of brickwork, this must also pass through the fans. The fan must be of sufficient capacity to deal with the hot gases with a margin of safety, and capable of producing a vacuum of about 1.5 inches of water at the bridge wall, dependent, of course, on the fuel to be used and the amount of forcing to which the boilers will be subjected. In addition, the flue and economizer friction must be overcome and suffi-

cient pressure generated to discharge the gases freely into the air; this usually calls for a suction equivalent to about 2.50 inches of water at the fan when economizers are used, but owing to the fact that each installation possesses features peculiar to itself it is not advisable to give fixed data.

The advantage of induced draft over forced draft is that it does not require any stack to carry off smoke: in the former case the stack, which is in reality only a delivery

TABLE VII. — WEIGHTS OF AIR, VAPOR OF WATER, AND SATURATED MIXTURES OF AIR AND VAPOR.*

At Different Temperatures under the Ordinary Atmospheric Pressure of 29.921 Inches of Mercury.

Temperature Fahrenheit.	Volume of Dry Air at different temperatures, the volume at 32° being 1.000.	Weight of a Cubic Foot of Dry Air at different temperatures, in pounds	Elastic Force of Vapor in inches of Mercury, Regnault.	Mixtures of Air Saturated with Vapor.						Cubic Ft. of Vapor from 1 lb. of Water at its own pressure in column 4.
				Elastic Force of the Air in the Mixture of Air and Vapor in ins. of Mercury.	Weight of Cubic Foot of the Mixture of Air and Vapor.			Weight of Vapor mixed with 1 pound of Air, in pounds.	Weight of Dry Air mixed with 1 lb. of Vapor, in pounds.	
					Weight of the Air in pounds.	Weight of the Vapor in pounds.	Total Weight of Mixture in pounds.			
1	2	3	4	5	6	7	8	9	10	11
0°	.935	.0864	.044	29.877	.0863	.000079	.086379	.00092	1092.4	....
12	.960	.0842	.074	29.849	.0840	.000130	.084130	.00155	646.1	....
22	.980	.0824	.118	29.803	.0821	.000202	.082302	.00245	406.4	....
32	1.000	.0807	.181	29.740	.0802	.000304	.080504	.00379	263.81	3289
42	1.020	.0791	.267	29.654	.0784	.000440	.078840	.00561	178.18	2252
52	1.041	.0776	.388	29.533	.0766	.000627	.077227	.00819	122.17	1595
62	1.061	.0761	.556	29.365	.0747	.000881	.075581	.01179	84.79	1135
72	1.082	.0747	.785	29.136	.0727	.001221	.073921	.01680	59.54	819
82	1.102	.0733	1.092	28.829	.0706	.001667	.072267	.02361	42.35	600
92	1.122	.0720	1.501	28.420	.0684	002250	.070717	.03289	30.40	444
102	1.143	.0707	2.036	27.885	.0659	.002997	.068897	.04547	21.98	334.
112	1.163	.0694	2.731	27.190	.0631	.003946	.067046	.06253	15.99	253
122	1.184	.0682	3.621	26.300	.0599	.005142	.065042	.08584	11.65	194
132	1.204	.0671	4.752	25.169	.0564	.006639	.063039	.11771	8.49	151
142	1.224	.0660	6.165	23.756	.0524	.008473	.060873	.16170	6.18	118
152	1.245	.0649	7.930	21.991	.0477	.010716	.058416	.22465	4.45	93.3
162	1.265	.0638	10.099	19.822	.0423	.013415	.055715	.31713	3.15	74.5
172	1.285	.0628	12.758	17.163	.0360	.016682	.052682	.46338	2.16	59.2
182	1.306	.0618	15.960	13.961	.0288	.020536	.049336	.71300	1.402	48.6
192	1.326	.0609	19.828	10.093	.0205	.025142	.045642	1.22643	.815	39.8
202	1.347	.0600	24.450	5.471	.0109	.030545	.041445	2.80230	.357	32.7
212	1.367	.0591	29.921	0.000	.0000	.036820	.036820	Infinite	.000	27.1

* By courtesy of the B. F. Sturtevant Co., Boston.

duct, may be run only a few feet above the roof as stated; in the latter case, however, a stack must be of sufficient height to overcome the friction in the smoke flues, etc. The disadvantage of induced draft is that the blower, etc., is more expensive, as provision has to be made to deal with high temperature, since the blowers are placed between the boiler and the stack.

TABLE VIII. — VELOCITY CREATED.*

When Air under a Given Pressure in Inches of Water is Allowed to Escape Into the Atmosphere.

Pressure in Inches of Water, per Square Inch.	Velocity of Dry Air at 50° Temperature Escaping into the Atmosphere through any Shaped Orifice in any Pipe or Reservoir in which the Given Pressure is Maintained.		Pressure in Inches of Water, per Square Inch.	Velocity of Dry Air at 50° Temperature Escaping into the Atmosphere through any Shaped Orifice in any Pipe or Reservoir in which the Given Pressure is Maintained.	
	In Feet per Second.	In Feet per Minute.		In Feet per Second.	In Feet per Minute.
0.1	20.72	1,243.3	2.6	105.33	6,320.0
0.2	29.30	1,758.0	2.7	107.33	6,439.7
0.3	35.84	2,150.4	2.8	109.28	6,557.0
0.4	41.43	2,485.6	2.9	111.21	6,672.3
0.5	46.31	2,778.7	3.0	113.09	6,785.5
0.6	50.73	3,043.5	3.1	114.95	6,896.8
0.7	54.78	3,287.0	3.2	116.77	7,006.3
0.8	58.56	3,513.5	3.3	118.57	7,114.1
0.9	62.10	3,726.1	3.4	120.34	7,220.2
1.0	65.45	3,927.2	3.5	122.08	7,324.7
1.1	68.64	4,118.4	3.6	123.80	7,427.7
1.2	71.68	4,301.0	3.7	125.49	7,529.3
1.3	74.60	4,476.1	3.8	127.16	7,629.4
1.4	77.41	4,644.5	3.9	128.80	7,728.2
1.5	80.12	4,806.9	4.0	130.43	7,825.7
1.6	82.73	4,963.9	4.25	134.40	8,064.1
1.7	85.27	5,116.1	4.5	138.26	8,295.4
1.8	87.73	5,263.7	4.75	142.00	8,520.1
1.9	90.12	5,407.3	5.	145.65	8,738.8
2.0	92.45	5,547.1	5.25	149.20	8,951.8
2.1	94.72	5,683.4	5.5	152.66	9,159.7
2.2	96.94	5,816.5	5.75	156.05	9,362.8
2.3	99.11	5,946.4	6.	159.35	9,561.2
2.4	101.23	6,073.6	6.25	162.59	9,755.4
2.5	103.30	6,198.1	6.50	165.76	9,945.8

* By courtesy of the B. F. Sturtevant Co., Boston.

Steam Blower. — Steam blowers are installed for each individual boiler and long air ducts are avoided. The steam assists in preventing the formation of clinker and is not undesirable in small amounts, but when large quantities of steam are used in an attempt to force the fire by thus increasing the air supply, the steam will rapidly deaden the fire. Lack of knowledge on this point has often resulted in much trouble. The steam jet at its best is, however, an inefficient method of moving air, and a suitable fan will be more economical.

SMOKE FLUES.

Character. — Smoke flues should be made as short and direct as possible; all turns should be avoided, and wherever these are found necessary they should be of the largest radius permissible, as already pointed out under chapter on draft. Long flues, or flues containing many crooks or bends, offer great resistance to the passage of the gases and cut down quite appreciably the draft pressure. For instance, a 90° turn may equal in resistance about 50 feet of straight flue. The location of flue, whether below, above or on the side of the boilers, is a matter of opinion, and depends largely on the type of boiler selected. European practice is usually to place the flues below the boilers. In this case the flues are constructed of masonry. American practice is generally to place the flue above the boilers; usually they are constructed of steel or iron and either carried directly on the boiler setting or supported from the building structure above. A lining is occasionally provided of brick or some fireproof material. Sometimes, in addition, flues are covered with asbestos blocks. The omission of the interior lining will reduce the first cost considerably, not only on account of the cost of the lining itself, but also because of the reduced size of flue.

Shape. — Owing to limited space and other requirements, such as the facilities for connecting to chimney, branch flue connections, cleaning doors, etc., overhead flues are generally made either square or rectangular in section. Frequently, however, they have circular tops. A square section, with circular or arched top, constitutes about the best form of steel flue, since the circular top requires no stiffening of itself, and adds a great deal of stiffness to the flue, and the remaining three sides offer ample opportunities for connection and easy lining. The square section here offers less resistance to the passage of gases than would the rectangular section of the same area, since the perimeter is a factor of the friction. The circular or arched top also adds less resistance than would the flat top. The steel flue is easily supported on the boiler setting or on structural steel.

Size. — For proportioning the main flues it is customary to allow from 2.75 to 3.5 square feet sectional area for 1,000 square feet of boiler heating surface. In selecting just the proper size of flue for any particular case, cognizance must be taken of the type of boiler to be used and the kind and quality of coal to be burned. A low-grade coal, because of the greater excess of air to be carried away, requires larger flues than a better quality of coal. Also a bituminous or long-flame coal, for practically the same reasons, will require an addition to the size of the flues over that required for hard or short-flame coals. Extended practice throughout America and European countries has well established the above given limits of 3.5 square feet for very poor coal and 2.75 square feet for the better class of coals. Another convenient and sufficiently accurate rule for determining the size of the main smoke flue is to make this from 20 to 25 per cent less than that of the chimney. Where mechanical draft is provided the size of the smoke flue may be 30 per cent less than that above given.

The size for uptakes and branch connections between the boilers and main smoke flue are generally given by the manufacturers and found to be larger in proportion than the main flue, as designed according to the above rules. It is not advisable to reduce this area, inasmuch as the additional space serves to offset the friction due to sharp turns, dampers, etc.

Expansion Joints. — Steel flues are sometimes provided with expansion joints, and this is quite necessary in flues of considerable length. In cases where such precautions

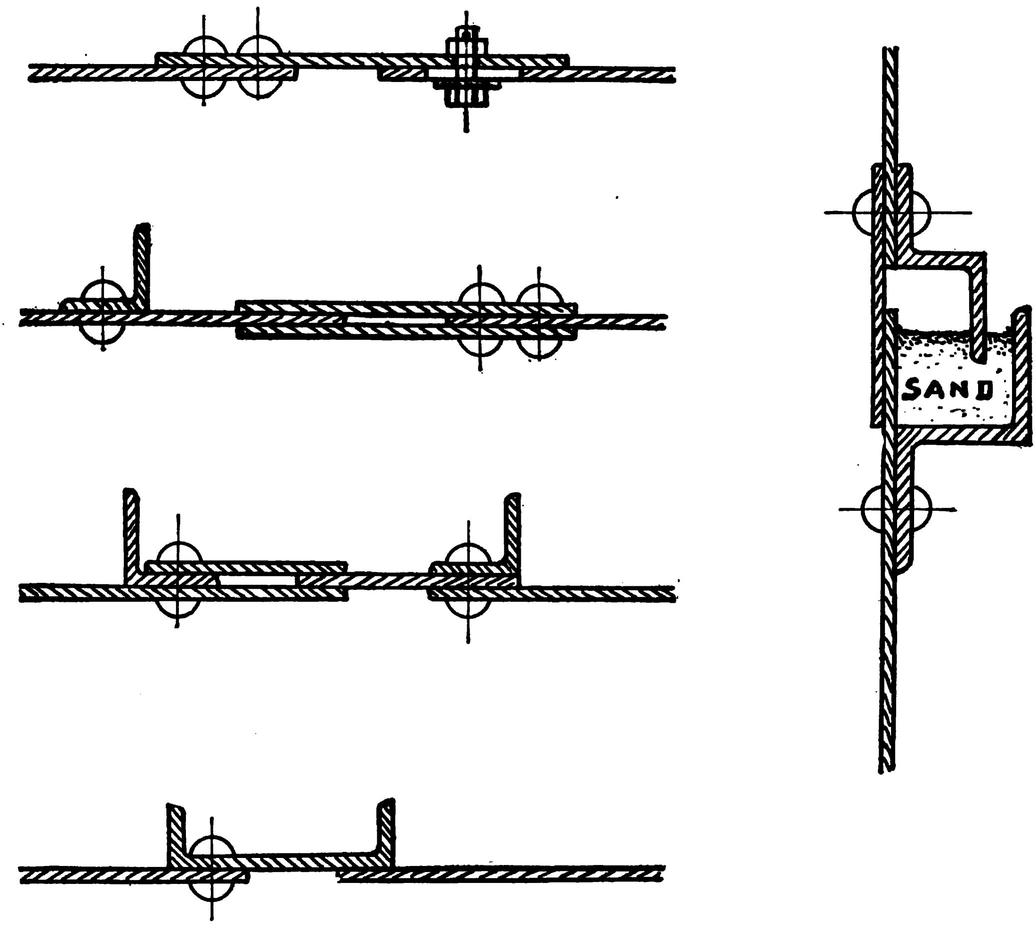


FIG. 1. Expansion Joints.

are not taken the constant expansion and contraction, due to temperature changes, may easily cause leakage or even break the joints or destroy the flue. Some of the common forms of expansion joints are shown in the accompanying illustration, Fig. 1. A more expensive, but very efficient form of joint, which can only be used in vertical flues, however, is shown at right hand of the same figure. This form of joint has been

made use of in the 59th St. power house of the New York Rapid Transit Co. In this installation each of the seventy-two 650 horse-power B. & W. boilers is provided with two lined uptakes, 4 feet 3 inches external diameter, and provided near their tops with a sand expansion joint illustrated above. Similar joints are being installed in the smoke flues for the new Potomac power plant, Washington, D.C.

Leakage.—Flues should be made air-tight and all joints and connections should be well fitted, caulked and riveted to prevent the leakage of air. Too much attention can hardly be paid to this point, since small leakages distributed over the area of a long flue will greatly impair the draft. Such a case has recently been observed by the author, where the leakages in the steel flues and radiation reduced the draft from one inch at the stack bases to one-fourth of an inch in the boiler settings.

Doors.—All flues should be amply provided with substantial and accessible clean-out doors. These doors should be tight fitting and provided with strong hinges and fasteners. In cases where doors and frames are not planed to accurate fits, air-tight joints may be made with gaskets of asbestos or some similar material.

Dampers. — The branch flues as well as main flues should be provided with dampers. These dampers may either be of the sliding or rotating form, but in either case should be easily operated and tight fitting. Dampers may be either hand operated or automatically operated by fluctuation of the steam pressure. Hand-operated dampers should have the operating mechanism well within reach, and arranged to clamp the damper in any position from open to closed. In the case of automatically operated dampers, a series of boilers may be controlled from one automatic damper regulator, which, in turn, is controlled by the pressure of the main steam header. In such an arrangement the individual dampers would be linked together and worked by a common connecting bar. Some care must be exercised with this arrangement to set each individual damper according to the amount of draft required by its boiler, as shown by any peculiarities it may have when in service.

Generally speaking, each branch flue should be provided with a damper, and in addition one main damper should be provided for each main flue near the point where it enters the chimney. The damper in the main flue is especially necessary where more than one flue enters the chimney, in order that repairs may easily be made on a flue without closing down the entire plant. The main dampers may also be operated automatically. Wherever possible the mechanical operation of dampers should be adopted, since in this manner a great saving of coal may be made during the life of the plant, without any very appreciable addition to first cost. This saving has been shown to range from 5 per cent to 10 per cent, depending, of course, upon the manner in which the firing is done and the hand-operated dampers are attended to. This saving is due to the draft being accurately regulated to suit the fire requirements.

Automatic Regulator.—There are a great many of these appliances to be found on the market in America, as well as in European countries, and for the most part they

give good results in operation. They are controlled primarily by the pressure in the main steam piping, and the damper operating mechanism so controlled is, in turn, operated by the pressure of a fluid. The following illustration, Fig. 2, will serve to

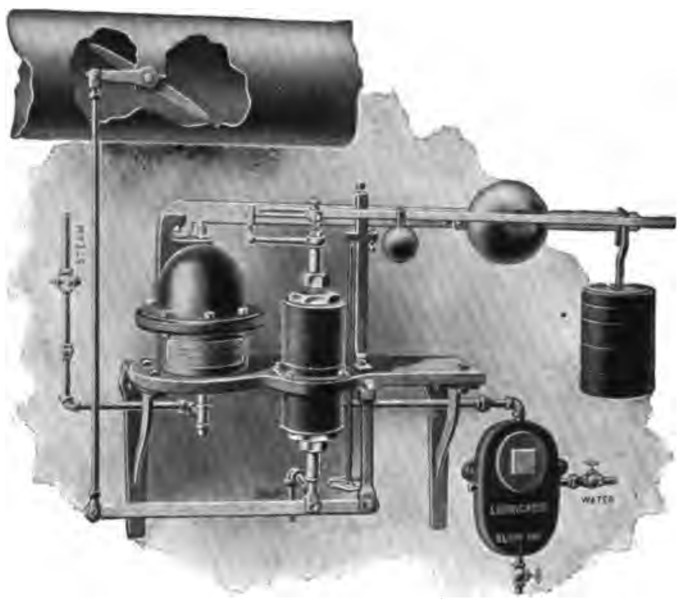


FIG. 2. Thompson Damper and Pressure Regulator.

show the general construction of a damper regulator which is sensitive in its operation. This appliance is known as the Thompson automatic damper and pressure regulator. The principle upon which this works is essentially as follows:

The pressure is taken directly from the boiler, steam pipes, or in cases where a series of boilers are to be controlled, from the main steam header, and led directly to the under side of the piston, shown near the fulcrum of the long levers. The piston rod is carried through guides, operated on the under side of the long lever, which is balanced on the opposite end by weights, as shown. Variations in the steam pressure cause the piston to move up and down, which, in turn, moves this corresponding lever. Attached to this first lever is a second lever which operates a pilot valve. This pilot valve controls the flow of the operating medium to a second cylinder, which is also provided with a piston connected to a lever near the bottom of the apparatus. This latter lever is then connected to the damper or dampers, to be operated through connecting links or chains. The use of chains here requires the addition of counterweights on the damper lever.

Any size of damper up to 6 x 12 feet, or even larger, has been successfully operated by a regulator of this type, and any number of dampers up to twenty may be so operated on one system. These regulators are ordinarily operated by water from the city mains. In cases, however, where a number of dampers are to be operated from the

same machine, it has been found necessary to use a water pressure in excess of the ordinary pressure on city mains, which is about 40 pounds. In the case of the Long Island City power plant of the Pennsylvania Railroad, for instance, it has been found necessary to use a pressure of 80 pounds per square inch in the operating cylinder of the regulator. In this particular case, however, the dampers for sixteen 525 horse-power boilers are operated from one machine.

Damper regulators are generally constructed, and set to operate on a pressure variation in the steam pipes of from 1 to 2 pounds. Very delicate apparatus of this kind has been made to operate on a pressure variation of ½ pound. In the matter of making the pressure variation as small as possible, it is very essential to have the dampers move easily on their bearings. Ball-bearing dampers or dampers suspended on a vertical chain are good. In any case a vertical axis revolving damper offers an advantage, inasmuch as the friction is not so great in this type as with horizontal pivoted dampers.

In addition to operating the flue dampers, the above-described apparatus is frequently connected so as to control the mechanical draft to the boiler. The blower

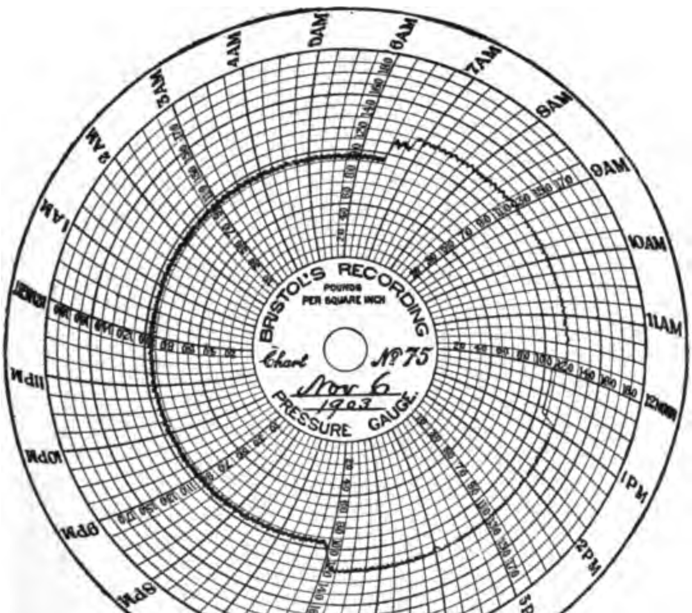


FIG. 3. Boiler Pressure Record. The Flue Dampers are Equipped with an Automatic Regulator.

may be operated in this case either by a steam engine or an electric motor. In case of the steam-operated fan, a regulating valve is inserted in the steam supply, and the regulator connected to this. In case of a motor, the regulator is connected to a suit-

able motor controller. The accompanying chart, Fig. 3, shows a record of the steam pressure taken from a plant where both dampers and fan were controlled by the above-mentioned appliance. It will be noticed here that the steam pressure during the day was held very evenly at 120 pounds, and during the night at 90 pounds; these being the respective pressures required during the day and night.

CHIMNEYS.

Character. — In order that good combustion may be obtained it is necessary that sufficient draft be supplied, which may be done either by natural or artificial methods: the former being secured by a sufficient height of chimney, and the temperature difference between gases and atmosphere; the latter by mechanically forced or induced draft. A chimney serves two purposes: first, to produce draft in supplying a certain amount of air to the boiler grate; and secondly, to carry off the gaseous products of combustion. The first is accomplished by the height and temperature difference, and the second by the internal area of the chimney, being based upon the amount and character of fuel to be consumed, the arrangement of the boilers with respect to the stack, and finally the location and altitude of the power plant itself.

Chimneys are supposed to be air-tight structures with vertical smooth flues, to carry off the gaseous products from the furnace, which should be discharged at such a height as to secure thorough diffusion in the atmosphere. They should be also designed to maintain a passage of air through the fire sufficient to insure perfect combustion of the fuel. Round chimneys are more efficient in producing a draft than those of square section. It is, therefore, natural that there should be in the market today a number of different makes of specially designed radial brick for the construction of chimneys. Common bricks for the construction of round chimneys are practically obsolete, owing to the large amount of clipping required and also the quantity of mortar required in the construction.

Material. — In modern power plants these different types of chimneys are in general use:

First. The brick chimney, usually of radial brick.

Second. The steel chimney, frequently lined with brick.

Third. The concrete chimney, reinforced with iron or steel.

The radial brick is in much more common use in the construction of power plants on the Continent, where it originated, the steel stack being much more common in Great Britain and America, which may be due to the fact that the plants on the Continent are designed for a longer life than those in other countries, it being the opinion of continental engineers that steel stacks are appropriate for temporary work only. The concrete chimney is of recent date, but has already acquired a prominent place in power plant construction in American practice. Octagonal chimneys are frequently employed in Great Britain, the interior section, however, being circular. This practice is peculiar to Great Britain.

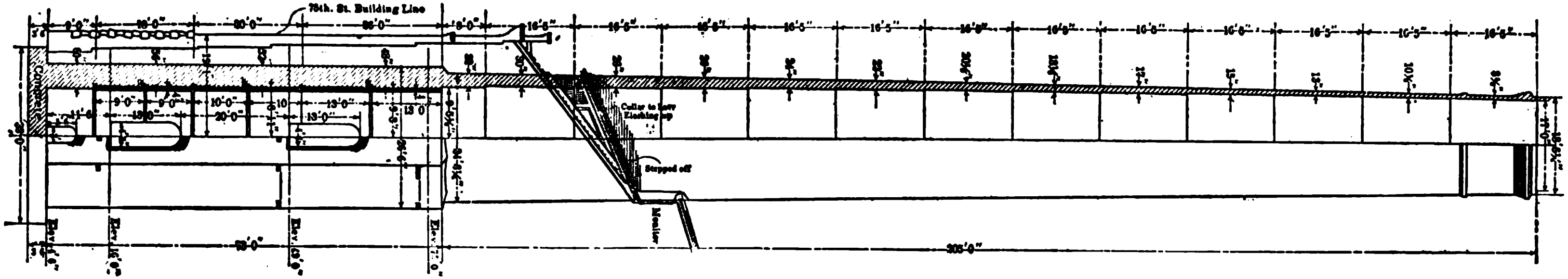


FIG. 1. Custodis Radial Brick Chimney, 74th St. Plant, New York.

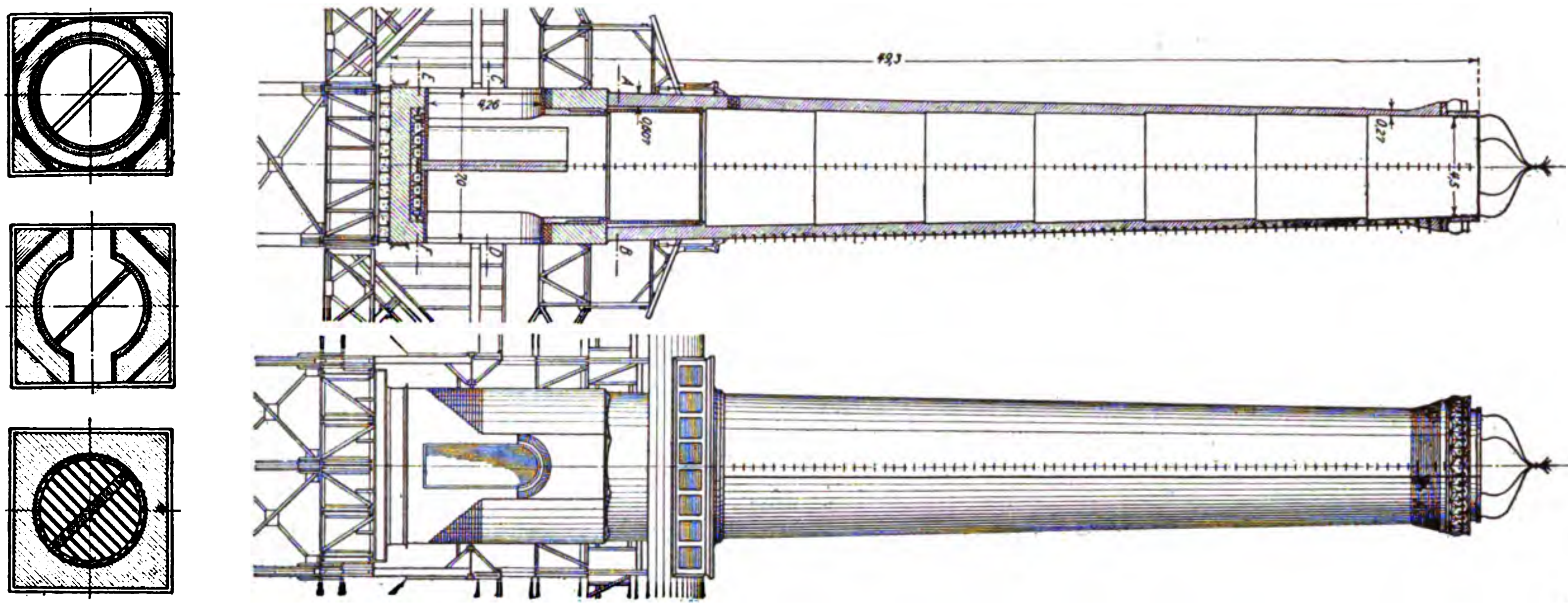


FIG. 2. Radial Brick Chimney, 59th St. Plant, New York (*Zeitschrift des Vereines deutscher Ingenieure*).

The item of cost must be determined after the consideration of many points, viz., the size, location and time taken for the erection. A steel stack may be more expensive in first cost than a brick chimney, if it is to be erected where the transportation charges on the material are excessive, even though the manufacturers' charges are extremely low. This, of course, assumes a locality advantageous for the delivery of bricks and mortar.

The items affecting the cost of different chimneys may be given briefly as follows:

I. Size.
II. Character.
III. Location.
IV. Foundation required.
V. Flue connections.
VI. Economizers, whether or not to be placed in the flues.

Which of the three types of chimney fulfills its duty best, and which is the most efficient, is a question with widely varying answers, which may be seen from the following opinions of the advocates of the different kinds. A brick chimney is made up of thousands of single bricks held together by mortar. As these are of different materials it is said that the influence of the weather will sooner or later produce innumerable cracks following the joints, in some cases invisible, but, nevertheless present, while these joints cannot be as smooth as that of a steel or concrete chimney. The over-all diameter of a radial brick chimney is greater than that of any other type.

A steel chimney made up of many plates, fastened together with numerous rivets, has a radiation loss greater than that of any other type. Should this chimney now be lined with brick, the inner surface would not be as smooth as the steel chimney alone, but exactly the same as a brick chimney. Frequent painting of the steel is necessary in order to prolong its life.

A concrete chimney is made up of a light shell, reinforced with a number of steel rods. On account of the lightness of these shells the common proportion of stone cannot be used, as it would result in a porous chimney. The steel reinforcement increases the radiation. The radiation through a concrete chimney is between that obtained with a non-lined steel chimney and a brick one, provided, of course, that none of them leak.

With regard to the appearance of the different types of chimney, it is the author's view that it is possible to obtain a much more elaborate architectural effect with a brick chimney than with any other at the same cost. However, the question of appearance is purely a matter of taste, whether it is of a tall massive shaft (brick) or a tall and thin one (steel or concrete). A businesslike appearance is claimed for the steel stack. This, however, is probably not the chief cause for its adoption in America, the first cost being usually of paramount importance.

It will be seen that the different types of chimney have advantages as well as disadvantages, and it must be remembered that when one secures an advantage, a disadvantage will be inevitable, and the only question to be answered is, does the former

outweigh the latter? If a power plant designer is to build a plant according to his own judgment the following may be of assistance.

Radial Brick.—The radial brick chimney is made up of radially formed bricks which are usually perforated in order to permit a more thorough burning in manufacture, thus increasing the density and strength and at the same time reducing the weight. This perforation forms a space in the walls of the chimney, preventing a certain amount of radiation, and forming the mortar into numerous dowels, making a very firm bond between the courses. These bricks are of hard burned pure clay, and generally require no lining of fire brick, although this is sometimes found in power plant practice. The chimney is usually wider at the bottom than at the top, and offset in sections inside, while the outside is a smooth conical shaft. The purpose of the enlarged internal diameter at the base of the chimney is, in part, to allow for the increased space occupied by the hotter gases, and to reduce the friction. These radial brick chimneys are always designed with a shell 7 to 8 inches thick at the top, the thickness at the base, of course, varying directly with the height. The shaft taper is about $3\frac{1}{2}$ feet in 100 feet outside and 1 foot per 100 feet inside. A chimney 200 feet high and 12 feet diameter at the top, having a shell thickness of $7\frac{1}{2}$ inches, would have an outside diameter at the base of 20 feet 3 inches, and an internal diameter of 14 feet. In addition to this, space must be allowed in laying out the power plant for the square or octagonal base frequently found with this type of brick chimney, either in the building or in the yard. In several large American plants brick chimneys have been erected on elevated platforms supported by the building columns and spanning the central firing aisle; as these columns also have to support the boilers and the coal bunkers, a very heavy construction is necessary. Notable instances of this practice are the Interborough power house in New York City, and the two later designed generating stations of the New York Central Railroad at Port Morris and Yonkers, N. Y. An advantage of this construction is that valuable floor space is not sacrificed, and all the space on the boiler floor is available, but at the same time the bunker space above the boilers is greatly reduced, and a number of expensive bunker bulkheads are necessary. Two distributing coal conveyors are required properly to fill the bunkers to their capacity, thus making it necessary to duplicate certain portions of the equipment in order to guard against possible shut-downs.

At the New York Interborough Subway power plant there are five chimneys of this construction at present erected, and provision is made for a sixth stack. The general dimensions of these chimneys are as follows:

Height above grates in feet	225′—0″
Diameter at top	15′—0″
Base of chimney above grates	63′—0″

Weight of stack about 1,200 short tons.

Each stack serves twelve 6,000 square feet Babcock & Wilcox boilers; economizers are provided for and forced draft is installed.

The supporting platform is carried by six columns and is composed of seven single-webbed girders, eight feet deep, two longitudinal and five lateral. These girders are surmounted by fourteen 20-inch I beams filled with concrete, forming a solid mat upon which the brickwork of the chimney stands. See illustration Fig. 2 from an article by the author.* As these chimneys have sufficient weight to resist the wind pressure an anchorage is unnecessary.

The octagonal base of the chimney rests upon a square pedestal placed upon the concrete mat and is surrounded by steel curbing for a height of three feet. At the top of the steel work is a layer of waterproofing, covering the interior area, upon which are two courses of brick; over these are built diagonal brick walls 4 inches thick, 12 inches apart and about 18 inches high. These walls are perforated at intervals, and the whole area is covered with perforated hard burned terra cotta blocks forming a cellular air space which communicates with the surrounding air and serves as an insulator for the protection of the steel work beneath. The bottom of the shaft is covered with a single course of fire brick and is level with the bottom of the flue openings, between which is placed a baffle wall at an angle of 45° carried 4 feet above the top of the flue openings. The shaft of the chimney has a thickness of 24 inches at the bottom, decreasing in eight regular sections to 8⅝ inches at the top. The flue openings are lined with fire brick, as is the lower portion of the chimney, for about 40 feet. At the roof provision is made by which the steel framing does not come in contact with the chimney, and metallic flaring on the chimney is bent over a hood with louvers upon the roof to exclude rain.

Reinforced Concrete. — The extended use of concrete in power plant construction is more noticeable every day, and it is therefore but natural that its employment for chimney construction should be seriously considered, and in fact a great number of reinforced concrete stacks have been placed in service. These chimneys are generally constructed with an inner and an outer shell and an annular air space. In some types the inner shell extends entirely to the top of the shaft and in others it extends for only a portion of the height. The purpose of the two shells is that one only is acted upon by the gases, and subjected to heat, the outer shell being practically protected by the air space, the latter shell being only exposed to atmospheric conditions. Each shell is thus free to expand independently under temperature changes which affect it alone. These chimneys do not necessarily require to be lined, as it is claimed that the concrete can withstand a temperature of 1,500° Fahr., which is much higher than they will ever be exposed to in power plant service. The shells have a thickness of from 4 to 9 inches, dependent upon the size of the chimney, and are reinforced by iron rods placed vertically and horizontally. As the chimney is of light construction, a thick foundation is not necessary properly to spread the load, but the area of the foundation must be large enough to provide sufficient stability to resist the overturning moment due to wind pressure, a factor which does not need to be considered in those cases where the weight of the chimney itself is sufficient to insure its stability. There-

* Zeitschrift des Vereines deutscher Ingenieure, March 4, 1905. "Das Krafthaus der New Yorker Untergrundbahn."

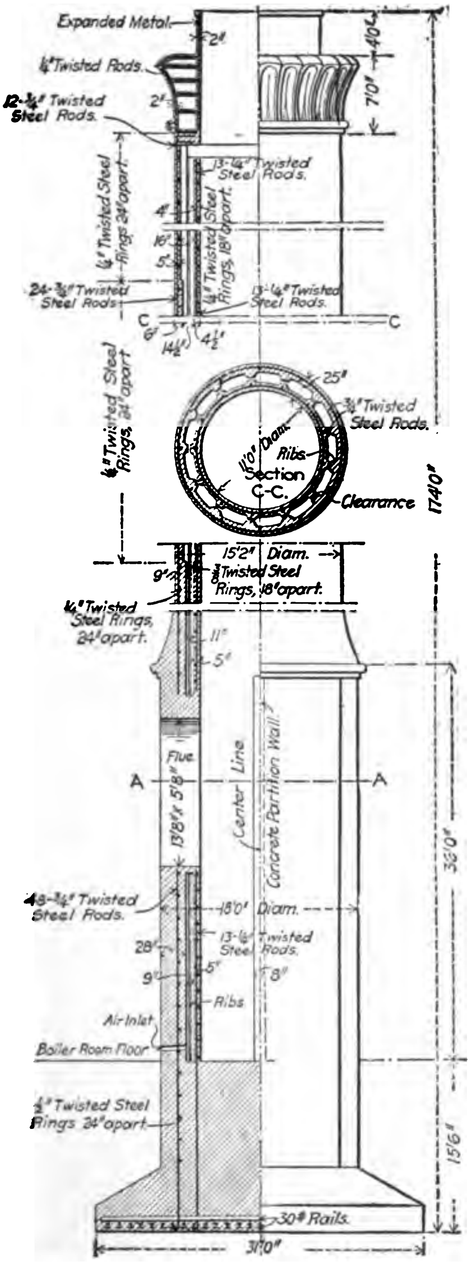


FIG. 3. Ransome Reinforced Concrete Chimney at the Pacific Railway Co's Plant, Los Angeles, Cal. (*Engineering Record*).

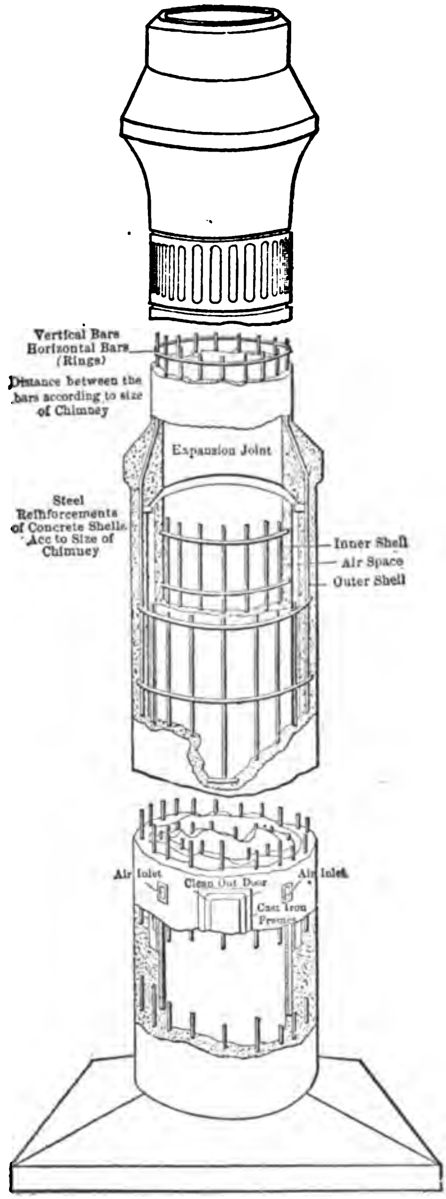


FIG. 4. Weber Reinforced Concrete Chimney (*Power*).

fore the reinforcing rods for the shaft must extend down into and be firmly anchored to the horizontal reinforcement in the foundation, which in this case acts in a similar manner to the bedplate used with steel chimneys. The footing is heavily reinforced by a grillage, composed of steel bars or old steel rails usually in two layers, laid at right angles to each other; diagonal grillages are sometimes employed.

With concrete chimneys the shaft is the same size throughout and the shaft is not tapered, but it is usual to make the base or pediment of a slightly larger outside diameter to a little above the flue openings, in order to provide against any weakening effect caused by the openings necessary at the base of the stack; above this offset the shell is of uniform thickness until it reaches the ornamental top. Two makes of reinforced concrete chimneys are shown so clearly in the accompanying cuts that an extended description is unnecessary. Fig. 3 shows the Ransom chimney of the Pacific Electric Railway Company of Los Angeles, Cal., in which twisted steel rods are used, and the foundation grillage is of old steel rails. Fig. 4 illustrates the Weber reinforced concrete chimney, in which the inner shell extends practically one-third of the height, provision being made for this to expand independently of the outer and to prevent soot dropping in the air space between the shells at this point. The vertical reinforcement used in this chimney consists of "T" irons. The horizontal rings consist of round rods spaced about 18 inches apart in the inner shell and about 3 feet apart in the outer shell.

The concrete used for chimneys is usually a 1:2:4 mixture, and to insure a smooth and impervious surface small stones must be used, such as will pass a $\frac{3}{4}$-inch and over a $\frac{1}{8}$-inch mesh. A very wet mixture is used and the stones are worked back from the surface. In some other types of concrete chimneys no stones are used at all; the mixture consisting of 1 part cement and 3 parts sand. The advantage of these types of chimney is their lightness and the ease and rapidity with which they may be erected.

Steel Chimneys.—There are two types of steel chimneys in use, the self-supporting and the guyed stack; the former is more commonly used for the larger plants, particularly in cities, while the latter is used for smaller plants in towns where room is available for anchoring the guys. Wire strands, cables and in some cases iron rods are used for guys. They are usually secured to a reinforcing ring at a height above the ground equal to two-thirds the height of the chimney and led off at an angle of 45° from the vertical: three or four guys are usually employed. In some cases two or more sets of guys are used when extremely light chimneys of considerable height are required; this type of construction being employed where, owing to extremely high transportation charges, and in some cases customs duties, it is desirable to cut down the weight to the lowest possible limit. An instance of this is the two chimneys of the Rand Central Electric Works near Johannesburg, South Africa. This station is located on a high hill, and the stacks, which are 10 feet in diameter, have a height of 165 feet. Each stack is provided with two guy rings, one about halfway up, and the other four-fifths of the height from the base, four guys being attached to each ring.

A peculiar method of guying a stack was developed to overcome unforeseen condi-

tions at the plant of the Mexican Electrical Works, Ltd., in the City of Mexico. This plant was designed and the equipment shipped from Germany. The stack was 9 feet 3 inches in diameter and 165 feet high, with a small bell-shaped base and was supplied with four guys. Upon its arrival it was found that only two of the guys could

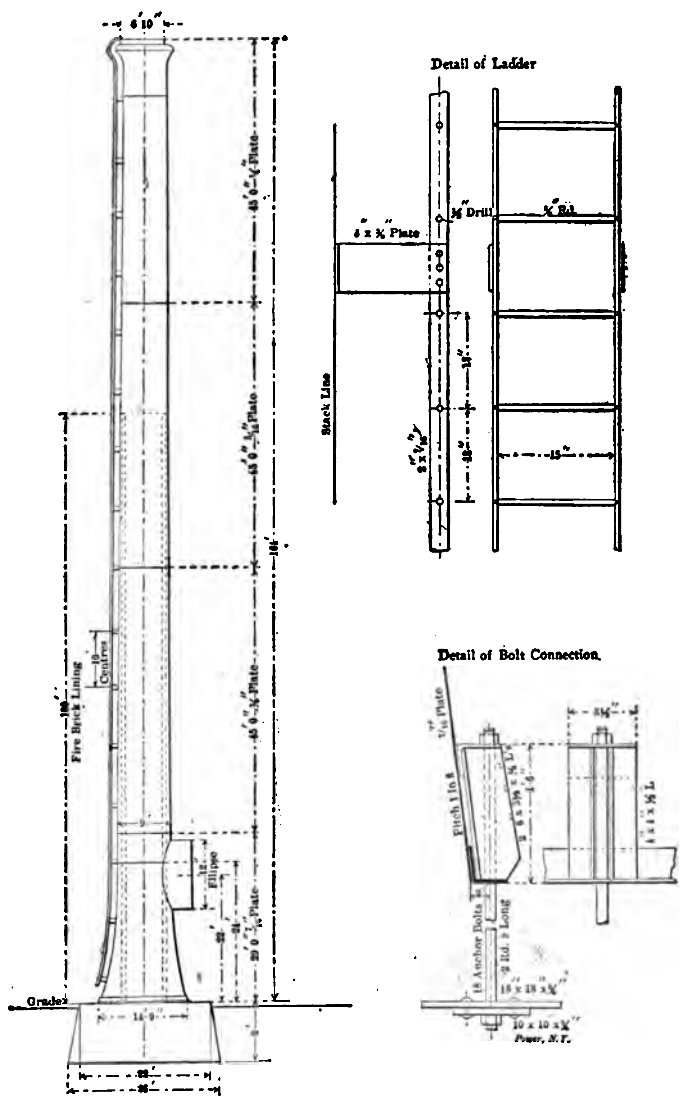


Fig. 5. Self-Supporting Steel Chimney (*Power*).

be anchored, as a street had been opened cutting off the other anchorages, and the following method was adopted for securing the stack. The guys were wrapped helically around the chimney and secured by turn-buckles to the foundation. This chimney, erected in 1897, is still in service in a country subject to earthquakes.

Owing to transportation difficulties it is not always advisable to use steel stacks for such plants, and at an electric plant at Para, Brazil, a brick stack was found less expensive, although the entire building was of steel frame construction with corrugated iron roof and sides.

Guyed Chimneys. — Guyed chimneys are usually straight cylinders, while self-supporting stacks have a conical base or bell. These chimneys are built in sections of convenient length, the thickness of the plate being usually ¼ inch at the top and increasing toward the base, usually each ring laps over the ring below. In this construction each ring is a section of a cone, although the taper is so slight as to be imperceptible, and the shaft is practically a cylinder. In some cases this practice is not fol-

FIG. 6. Steel Chimneys in Process of Erection, Long Island City Plant.

lowed, the rings being made straight with alternate inside and outside laps, in other instances the sections are assembled with the horizontal laps made by the lower ring coming outside of the upper, straight rings being used and a gradual taper is obtained for the shaft in this way. A trolley ring is frequently provided close to the top of the stack with a trolley and a block, by which a man can be hoisted when it is necessary to paint the stack. Ornamental galleries and railings are occasionally placed just below the top of the chimney.

Self-Supporting. — The base of self-supporting chimneys is bell-shaped, being flared out for a height of $\frac{1}{10}$ to $\frac{1}{8}$ the height of the chimney, the diameter at the base is from $\frac{1}{8}$ to $\frac{1}{12}$ of the height, but is often fixed by other considerations. The bell is occasionally proportioned on the diameter of the stack, the height being from $1\frac{1}{2}$ to $2\frac{1}{2}$ times the diameter, and the diameter of the base plate being from one and a half to twice the stack diameter. It will be noted that these two methods are substantially in agreement. A heavy circular cast-iron bedplate is used below the bell, the foundation bolts passing up through the bedplate, and steel brackets riveted to the shell. In some cases, however, the bedplate is secured to the foundation and the shell is riveted to it. The foundation contains a number of heavy anchor plates for the holding down bolts, or in some cases a grillage. This foundation must extend to a sufficient height above the ground to protect the stack and bedplates from ground moisture, and must be of sufficient area and weight to resist the wind-overturning moment.

Lining. — It is often claimed that where there is a long smoke flue between the boiler and the stack, it is unnecessary to line steel chimneys; this would be true if the deteriorating effect of the hot gases alone was to be reckoned with, but the province of the chimney is to provide a draft, and it can only do this when there is a sufficient difference in temperature between the internal column and the external air to provide head enough for this purpose. A large quantity of heat will be lost by an unlined stack, and such losses are much more serious when low stack temperatures are dealt with than when hot gases are handled. The duty of the lining is not only to prevent corrosion, but to act as a heat insulator.

There is a considerable variation in practice in regard to lining steel chimneys; in some cases only the lower portion, in others one-half the height is lined, and fully lined stacks are often used. The lower portion of the lining is fire brick, and this is sometimes continued for the full height; in other cases the upper portion of the stack is lined with hard red brick, the upper lining rarely exceeds $4\frac{1}{2}$ inches in thickness, and the thickness increases in regular steps to the base, the length of each section varying from 20 to 50 feet, according to circumstances. The regular practice is to allow an air space between the lining and the shell, though in some cases this space is filled with sand; in the stack of the Pennsylvania, New York & Long Island Railroad power plant a concrete backing is used. In some full and half lined stacks the lining is divided into a number of sections vertically, each ring having a depth of from 10 to 25 feet, and being supported by "Z" bars or angles riveted to the shell with an allowance for vertical expansion between the rings; such linings are usually the same thickness throughout their height. But in all cases the base of the stack is supplied with a heavier lining, owing to the hottest gases being at this point.

It is necessary that a chimney lining should be free to expand, particularly where it is exposed to hot gases, that is, provision of this character is more necessary at the base than at the top. All brickwork expands and contracts more or less under temperature variations, and where the attempt is made to rigidly confine this structure, it will work

itself to pieces and fall down in patches, resulting in serious local corrosion and weakening of the steel work.

One of the latest steel stacks built is that of the Long Island City power plant of the Pennsylvania, New York & Long Island Railroad. This stack has an internal diameter of 16 feet and is 275 feet high above the base.

These chimneys serve a double decked boiler house and are provided with six smoke flue openings and one opening for a cleaning door, and are unique in arrangement. The four upper flue openings are connected with economizers through which the waste gases pass. The two lower flue openings are in the boiler-room basement and connect with the by-pass flue of the economizers. The lower portion of the stack is separated into halves by a baffle wall. Immediately above the lowest flue opening a floor with a horizontal damper is placed in each half of the shaft, and the division wall below this floor is pierced by an opening supplied with dampers, the purpose of this arrangement being to by-pass any one of the chimneys should it be desired to do so. The bottom of the chimney is flared out to a diameter of 23 feet, and above the bell cylindrical rings are used, the upper plates in all cases telescoping inside the lower, so that a slight taper runs through the shaft. The upper edges of the rings are planed to a level, and during erection these joints were calked tight to prevent rain working in. A single brick lining is used throughout, and supported at 20 feet intervals by horizontal "Z" bar rings. The space between the lining and the shell was grouted full of cement mortar to protect the steel; in the bell the lining is backed by red brick for a height of 64 feet. The stack is riveted to a segmental cast-iron bedplate, held down by 20 3-inch anchor bolts which pass through, and are held by, a grillage of steel rails in the bottom of the foundation. The top of the chimney is finished by a segmental cast-iron astragal and a "Z" bar painting ring. Just above the boiler-house roof is a rain shield or flashing riveted to the stack. The rings were assembled at the shop before shipment and the rivet holes reamed. The complete equipment of four stacks was erected in about three and one-half months. This power plant rests on wood piling spaced 2 feet 4 inches centers, above which is a mattress of concrete 6 feet 6 inches thick over the entire building, increased at the stacks to a thickness of 8 feet 6 inches.

Baffle Wall. — Chimneys having two or more flue openings should be provided with baffle or division walls placed at an angle with the axis of the flues, usually at 45°, by which the two opposing currents of hot gases are turned up the stack with but slight loss of velocity, in a sort of a whirl, the office of the wall being principally to prevent the two currents of gas from impinging on each other, and thus reducing the efficiency of the chimney. These walls extend a few feet above the flue openings and in a two or three story boiler house the baffle wall should be continued up above the highest opening, though this is sometimes considered unnecessary, as was the case in the Pennsylvania, New York & Long Island chimney, described above.

Ladders. — Chimneys, no matter how constructed, should be provided with permanent means for climbing them. For a steel chimney a ladder is provided on the outside, and a boatswain chair must be used for painting or inspecting the lining.

Brick chimneys usually have a ladder inside, formed of suitable iron steps anchored in the brickwork, and in many cases an outside ladder of similar construction is provided; ladders of this kind can be used on concrete chimneys.

Lightning Arresters. — Protection from lightning comes within the same category as fire insurance, that is, it is simply good business policy. Lightning may never come near a chimney, but there is no reason for omitting the rod, any more than there is for omitting the fire insurance on goods stored in a fireproof building. A great many chimneys have been struck by lightning and badly damaged, if not completely destroyed. The damage in such cases is not confined to that done to the chimney itself, but adjacent property is damaged by falling débris, and in most cases the complete shut-down of the plant results. A steel chimney is, of itself, an excellent lightning conductor and protects all surrounding property. Brick and concrete chimneys are non-conductors, but the ascending current of hot gases presents a path tending to attract the discharge of atmospheric electricity. A number of methods are used for protecting them, ranging from a single point extending high enough above the chimney, in some cases 10 to 13 feet, to a number of points one foot high at intervals of two feet around the circumference of the top. When a single point is used it is sometimes counterweighted to keep it upright and arranged to be lowered, the supporting cable serving as the lightning conductor; or two cables may be used, one acting as a guy to keep the point vertical, the other serving to lower it. In some cases the chimney has a metal crown of decorative design which serves the purpose of the point on a lightning rod and is connected to earth in a similar manner.

Lightning rod points should be blunt cones, with a base radius equal to their height, and may be made from gilded copper, platinum, nickel plated copper, or iron gilded or nickel plated to resist oxidization. The conductor, if of copper, should weigh about 6 ounces per foot, and when in cable form no individual wire should be less than No. 12 B.W.G.; an iron rod should weigh $2\frac{1}{4}$ pounds per foot, and should be galvanized or tinned. All joints in the conductor should be soldered, for, although lightning can jump bad joints, it is better not to rely on such properties of discharge. The conductor should be free from abrupt bends and should be supported by insulated hangers of the same materials. It is led down the outside of the chimney, preferably near a ladder, for ease of inspection, as well as installation. When stacks are erected in steel frame buildings the lightning rod is sometimes grounded on the frame; this is not desirable unless the frame is also well grounded to the earth.

The ground connection should be made where the earth is permanently damp, or the conductor may terminate below the water in a well or other body of water. Copper ground plates are from $\frac{1}{16}$ to $\frac{1}{8}$ inch thick and iron plates $\frac{1}{4}$ inch thick, galvanized, and are preferably surrounded by crushed coke. They should have a total surface of from 18 to 20 square feet, or copper strips having an equal area may be laid in a trench surrounded by coke. The ground plate should be buried below the ground water line or near the discharge of rain-water leaders or other pipes tending to keep the earth moist when possible. In many cases two independent ground connections are insisted upon.

BOILER FEED WATER.

Pure Water. — Water in its natural state is never found absolutely pure, and absolutely pure water is impossible to obtain except by distillation. Requirements for different industries, in regard to water, vary so greatly that it would be impossible to establish a standard which would be valid in all cases; in industrial practice the highest degree of purity is not required, even if the cost of supplying pure water did not forbid. What is needed is not an absolutely pure water, but a suitable water. Not every water is suitable for boiler feeding. The question to be considered is, how to secure the best possible water available in the district where the boilers are used. Provided that no suitable water is obtainable, means can be adopted to purify it to a degree that will make its use economical.

Impure Water. — The feed water for the boilers must not injure the metal of which the boilers are built, it must be as free as possible from air, carbonic acid, salts of ammonia, decomposed foods, chlorides, etc., and it must not produce scale by the deposit of sulphates of lime, carbonate of lime, magnesia, alumina and iron, which not only reduce the efficiency of the boilers, but likewise, if neglected, render them dangerous. In addition to this, impurities cause considerable expense in the way of delay, cleaning and repairs, and the loss due to the necessity of blowing down at more frequent intervals than would be necessary had better water been supplied. In fact this blowing down of the boilers is one of the serious heat losses of the plant, while the amount of energy wasted in this matter is too frequently not recognized by power plant designers.

The amount of solids deposited in a boiler is often astonishing; over 300 pounds per month may be deposited in a 100 horse-power boiler, using water which shows only 7 grains of solids per U.S. gallon, and in some localities a boiler can only be operated two or three days between cleanings. The impurities met with in feed water may produce one or several of the following results:

I. Internal corrosion of the boiler.
II. Precipitation of mud, etc.
III. Formation of scale.
IV. Scum, which causes excessive priming or foaming.

Boiler Corrosion. — Pitting and corrosion are caused by free acids which are either in the original water or are liberated by the splitting up of some salt in the water. These acids may be of vegetable origin, derived from some adulterant of the lubricating oil used, or the original water may have been polluted with ashes from some neighboring industrial works or mine, or the water may have been taken from swamps or bogs which often contain humic or vegetable acids. Sulphuric acid is found in mine drainage, and is also absorbed from the atmosphere.

Air absorbed by water is freed by boiling and produces some corrosion. The peculiar activity of oxygen under such circumstances is perhaps due to the fact that

whereas ordinary air is a mixture of oxygen and nitrogen in the approximate ratio of 1 to 4, when the air is dissolved in water it becomes a mixture of 1 part oxygen and only 1.87 parts of nitrogen, owing to the greater solubility of oxygen. The result is that when this air is liberated there is a large amount of free oxygen which unites with the iron, usually forming pits of small area but of considerable depth. The activity of the oxygen is not rapid at high temperatures, but it attacks the iron most rapidly when the boiler is only in use a portion of the time, therefore there is more rapid corrosion in boilers where there are many shut-downs, and also in the feed-water pipes where the temperature falls within the range at which the oxygen is most active.

When alkaline water is used, it is very liable to attack copper fittings, particularly should the circulation be defective. The oxygen attacks the copper and the alkali dissolves the copper oxide so formed, whereby a fresh surface of copper is presented to the attacks of the oxygen. With such waters heavy boiler plates have been pitted through in a few months.

Mud. —When provision is made to catch the mud and blow it off before it settles on the heating surface the only evil effect is the cost of the heat lost. If this mud, however, is carried along and deposited on the heating surface, it may unite with the scale-forming materials present in the water, and the mass will be baked on the surface of the plates and tubes, forming a very hard scale which is costly and difficult to remove.

Boiler Scale. — The effect of scale depends largely upon its density. Those formed by carbonates are usually soft and porous, and their retarding effect upon heat transmission is small, except when present in large quantities. Sulphates and a few other impurities deposit a hard scale, so hard that they can only be removed by chipping or cutting them loose by some sort of a machine. These scales are impervious to water, and are a source of positive danger, because the metal upon which they have been deposited cannot transmit its heat to the water in the boiler, which is liable to burn, crack or should the metal reach a red heat, bulges will be formed, or possibly a partial destruction of the boiler will occur.

The following are the most common scale-forming materials:

Calcium (lime) Carbonate,	$CaCO_3$.	Calcium Sulphate,	$CaSO_4$.
Magnesium Carbonate,	$MgCO_3$.	Magnesium Sulphate,	$MgSO_4$.

The following materials are found usually in small quantities, and far less frequently than those first mentioned:

Iron Carbonate,	Fe_2CO_3.	Iron Oxide,	Fe_2O_3.
Magnesium Chloride,	$MgCl_2$.	Iron Hydroxide,	$Fe_2(OH)_6$.
Calcium (lime) Chloride	$CaCl_2$.	Calcium Phosphate,	$Ca_3(PO_4)_2$.
Potassium Chloride,	KCl.	Silica,	Si.
Sodium Chloride.	NaCl.		

and organic matter of various kinds.

Magnesium and calcium carbonate are but slightly soluble in water and are usually combined with carbon dioxide, forming bicarbonates of calcium and magnesia ($CaH_2(CO_3)_2$ and $MgH_2(CO_3)_2$), which are quite soluble in cold water. When this water is heated, the carbon dioxide (CO_2) is driven off, decomposing the bicarbonates and precipitating the comparatively insoluble mono-carbonate of lime and magnesium hydrate. This decomposition occurs between the temperatures of 180° to 290° Fahr. The scale formed by carbonate of calcium is comparatively porous and does not adhere strongly to metal, and is, therefore, not troublesome, unless present in large quantities. This is also true of magnesium carbonate alone, but this substance follows the water currents and settles very slowly, and when other substances are present it tends to cement them together, forming a more troublesome scale. These substances will often cause violent thumping in the boiler, which may have serious results. The magnesium and calcium sulphates are the most troublesome scale-forming impurities. They are not deposited until about the temperature of 300° Fahr. is reached. The magnesium sulphate deposits a mono-hydrated salt, and its presence is objectionable because it interferes with the removal of other impurities. Calcium sulphate is deposited in long needle-like crystals, which have active cementing properties, and when mingling with other matters form a very hard and troublesome scale.

The iron carbonate behaves in a similar manner to the calcium mono-carbonate, but it only occasionally occurs, and usually in such small quantities that its effects are negligible.

Magnesium chloride is deposited as a hydroxide, and as it has very active cementing properties it is decidedly objectionable.

The others, potassium chloride, calcium and sodium chlorides (common salt), give little trouble from incrustation, unless allowed to concentrate beyond the saturation point, when they are deposited and increase the bulk of the scale. They, however, possess no cementing properties in themselves, but may cause foaming, which will be greater as the specific gravity of the solution increases. The only remedy for these impurities is frequent blowing down, which prevents their concentration.

Scum. — Sewage and vegetable matter, when present in the boiler, form a glutinous skin on the surface of the water, which may be so serious as to interfere with the working of the plant. Some of these materials may be due to animal or vegetable compounds used as dilutents to the cylinder oil, which enter the boiler from the hot well and condenser. When soda compounds are used in the boiler, or contained in the feed water, these oils may be saponified, in such a case "soapsuds" and violent thumping are the result. A surface blow-off is a good method of handling scum, but such blow-offs are troublesome in operation.

Dervaux-Reisert Purifier. — The importance of the installation of water-purifying apparatus, where impure boiler feed water is to be used, is frequently grossly neglected by the power plant designer. The first cost of the water-purifying system is not of great importance, and the larger the plant the cheaper, comparatively. The cost

of maintenance is also low, as the price of the chemicals used is small, and it does not require close attention. This is in many cases due to the fact that their designers do not appreciate the benefit derived. It is the author's purpose to describe here an apparatus, several of which have been installed under his supervision, and excellent results obtained from the same.

The accompanying illustration, Fig. 1, represents an automatic water-purifying apparatus, as most generally used in Europe, and also in America. This apparatus consists of

I. A continuously acting Dervaux lime saturator;
II. Distributing apparatus;
III. Reaction chamber;
IV. Reisert gravel filter;

and is marketed in New York and London by the Hans Reisert Co., Ltd., of Cologne, Germany. The principle on which the apparatus is constructed is as follows:

Hydrate of lime (caustic lime) is the cheapest precipitant of all bicarbonates, and when calcined soda (carbonate of soda) is used at the same time it precipitates sulphates and other compounds much more cheaply than caustic soda, which is used in many other purifying processes. As lime cannot be dissolved like soda to any desired degree of concentration in water, and as milk of lime cannot be used continuously in equal quantities, the advantage is taken of the property of lime by which it becomes dissolved in the fixed ratio of 1:778 in the water and thus saturates the latter. Beyond this point water takes up no more lime in solution. The Dervaux lime saturator consists essentially of an upright conical vessel S, the smallest section of which is at the bottom. The previously prepared milk of lime (made by slaking and diluting the lime in the vessel J) is introduced through the stopcock K and the tube k into the bottom of the lime saturator after the exhaust lime residue has been drawn off immediately before through the cock L. An accurately regulated constant water supply flows from the regulating vessel R through the cock V and the tube v into the mass of lime, which has been introduced and gives it a continuous whirling motion. The water carries the lime upwards until the velocity of the water becomes so small, in consequence of the increasing cross-section, that the heavier particles of lime cannot follow. As a consequence the lime water, which has thus become completely saturated with lime, leaves the lime saturator in a clear state through the tube U. The particles of lime which fall back are, therefore, continually seized by the current of the water and whirled about until they are completely absorbed.

The lime water flows from the lime saturator into the mixing pipe E in the reaction chamber. Into this tube flow also the soda solution from the chamber C of the distributing apparatus by means of a siphon N and the crude water through the cock P from the chamber R. In this reaction chamber a part of the precipitated sediment is deposited, from whence it may be removed through the mud gate W from time to time. The water in chamber D rises slowly upwards and enters the top of the tube by which it is conducted to the Reisert filter F and then leaves the purifying apparatus

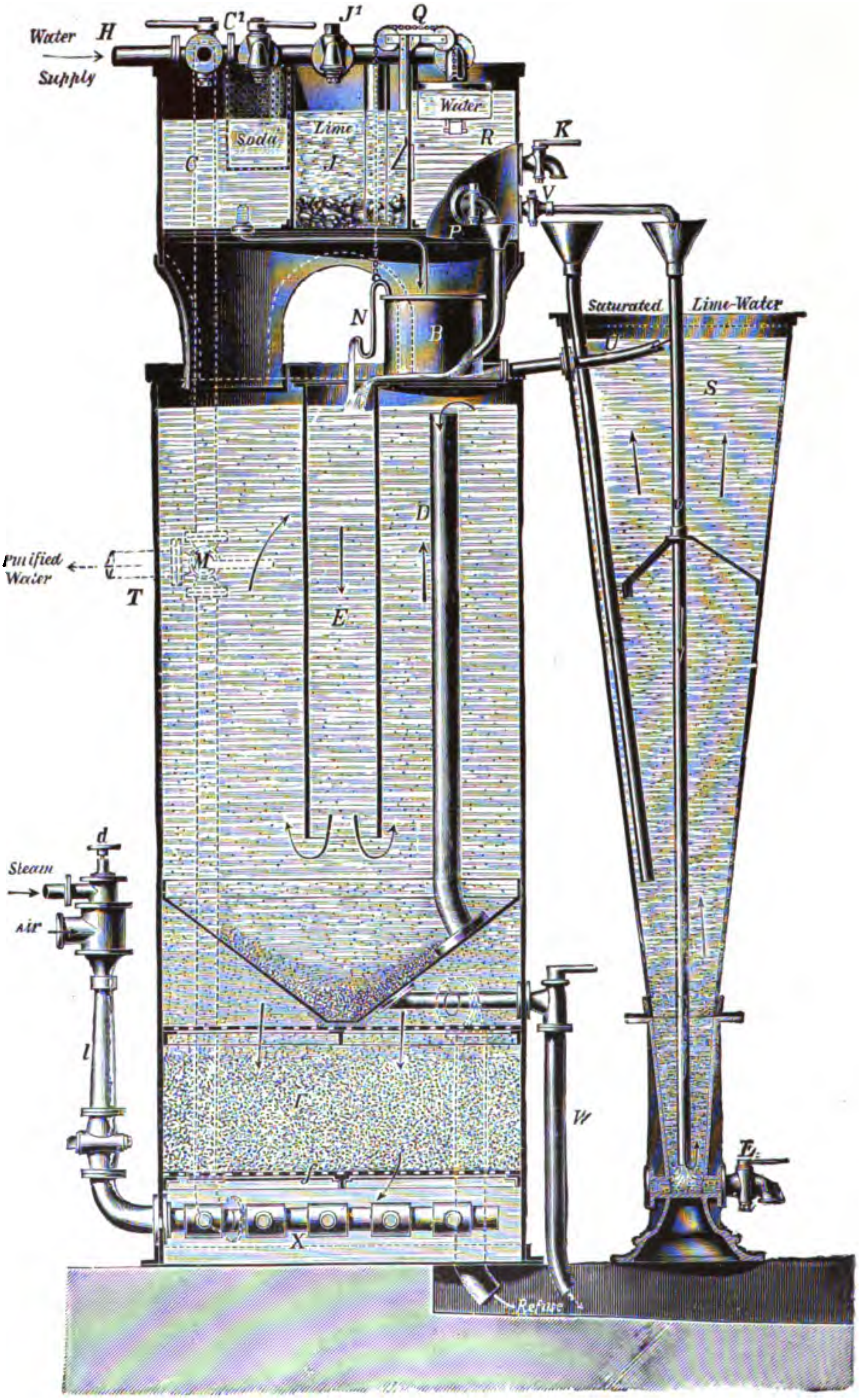


FIG. 1. Dervaux-Reisert Automatic Water Purifying Apparatus.

perfectly clear through the tube Z and the three-way cock M and is carried off by the waste pipe T. The material of the filter never needs renewing. It takes about five minutes to cleanse it, and this has to be done about once or twice a day or even less frequently, according to the quantity of mud. It is washed as follows:

Open the mud gate O and adjust the two three-way cocks in such a manner that the water flowing into the apparatus enters it through the pipe Z beneath the filter

FIG. 2. Automatic Water Purifying Plant (Dervaux-Reisert) of 12,000 gal. per hour capacity at the Power Plant of the Syracuse Lighting Co., Syracuse, N. Y.

material instead of entering the distributing chamber. Then turn on the air compressor. While the compressed air, which is led beneath the filtering material, stirs it up violently and loosens the mud particles, the water that flows back carries them along and takes them to the mud gate. The air compressor must be closed again after two or three minutes, but the water still allowed to flow until the water leaving by the mud gate O is quite clear. Then the three-way cocks M are put back again in

their original positions. The apparatus has been found especially useful in purifying waters which often change their composition and waters which contain much mud as river waters, for instance. The apparatus has also been used with the best results for the removal of oil from the water of condensers.

The accompanying illustration, Fig. 2, shows the purifying apparatus at the power plant of the Syracuse Lighting Company, Syracuse, N. Y. The water to be treated is taken from the Oswego Canal, which varies frequently in its character and at times shows a hardness of 25°, American. This purifying plant is of the above-described Reisert system and consists of two apparatus, one of which is shown in the illustration, each having an hourly capacity of 12,000 gallons. The power plant consists partly of turbines and partly of reciprocating engines; the water of condensation from the turbines is mixed with the make-up water, thereby raising the temperature of the water delivered to the filters, a smaller apparatus than otherwise necessary is therefore required.

An apparatus of still greater importance in modern power plant designing has recently been introduced in the market after being thoroughly tried in Germany by the same company. It is a modification of the above-described type. It needs even less attention and has the great advantage that it can purify water at any temperature. The chemicals to the former are supplied proportionately in an automatic manner, while for the latter system they may be supplied in a larger quantity for an extended period. The principal chemical used is barium carbonate. Apparatus of this kind have been installed at Frankfort-on-the-Main and elsewhere, and after being thoroughly tested were found to give satisfaction in every respect.

Storage. — Where boiler feed water is drawn directly from the city mains, surge tanks should be installed in order to procure for the pumps a steady water supply. These tanks, in smaller plants, are frequently located on the roof of boiler house; where, however, the tanks are too large for this they may be installed in the basement of the boiler room or outside of the building, in the latter case they may be located on an elevated structure. If these tanks are fed directly from the city mains, the discharge pipe into tanks should be provided with a float valve, in order to automatically cut off the supply when the water reaches proper level. If the city pressure is not high enough, or in case the water be drawn from wells, house pumps may be installed, discharging into the surge tanks. Where the city mains are provided with meters, the piping, before it enters the meter, should be provided with a screen, to remove any foreign substance.

FEED-WATER HEATERS.

Feed-water heaters may be classified as exhaust steam heaters and economizers. Exhaust steam heaters may be sub-classified as open and closed.

Open Heaters. — In open feed-water heaters the water is heated by direct contact with the steam. This may be accomplished in a variety of ways, by a spray, overflowing trays or an umbrella. If there is sufficient amount of exhaust steam, the water

may be heated to boiling point. However, with ordinary power plant conditions, where the amount of exhaust steam supplied by the auxiliary machinery is but a small percentage of the amount of steam delivered from the boilers, this high temperature is usually not obtained. The open feed-water heater should be placed at least four to five feet above the boiler feed pump, so that the hot water will flow by gravity to the suction valves, whence the water is pumped to the boilers. Most open feed-water heaters

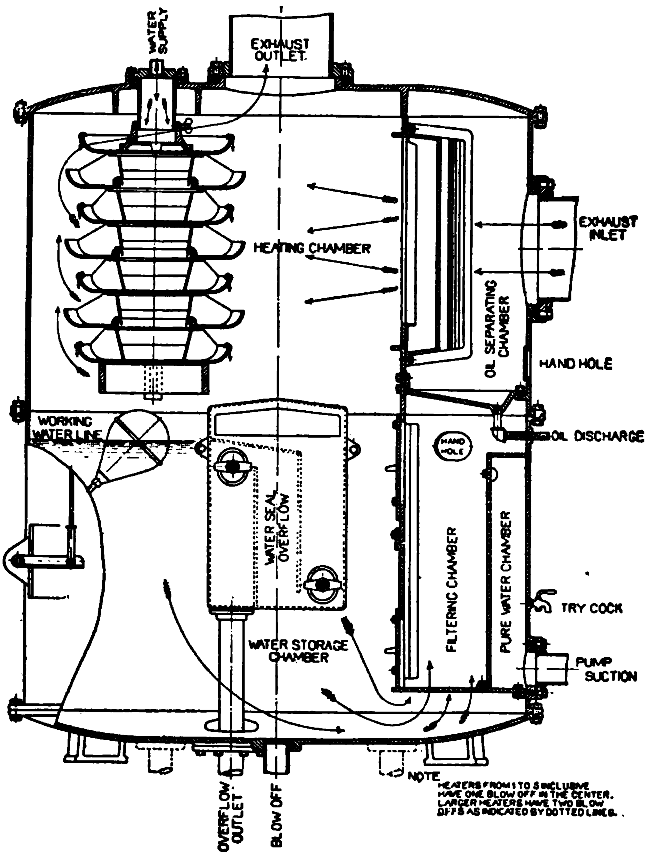


FIG. 1. Stillwell Open Feed-Water Heater.

are provided with an oil extractor for removing oil from the exhaust steam, so that it may not be sent to the boiler, therefore in installing an open feed-water heater sufficient clearance should be left for the removal and cleaning of the filters or trays, as the case may be.

Fig. 1 illustrates a Stillwell open feed-water heater. It is hardly necessary to describe the operation of this heater, as it is clearly depicted in the illustration. Other well-known open feed-water heaters are the Webster and Cochrane, the latter, which is especially adapted for the removal of oil, is shown in the accompanying illustration.

Closed Heater. — Closed heaters are designed for carrying the exhaust steam either through the tubes, or surrounding the tubes. In the former the shell, which is either made of cast iron or riveted steel plates, must be of considerable thickness so as to withstand boiler pressure, provided that the feed pumps discharge through the heater. In the other type of closed heater the shell may be made of light material, as it withstands no pressure other than that of the exhaust steam.

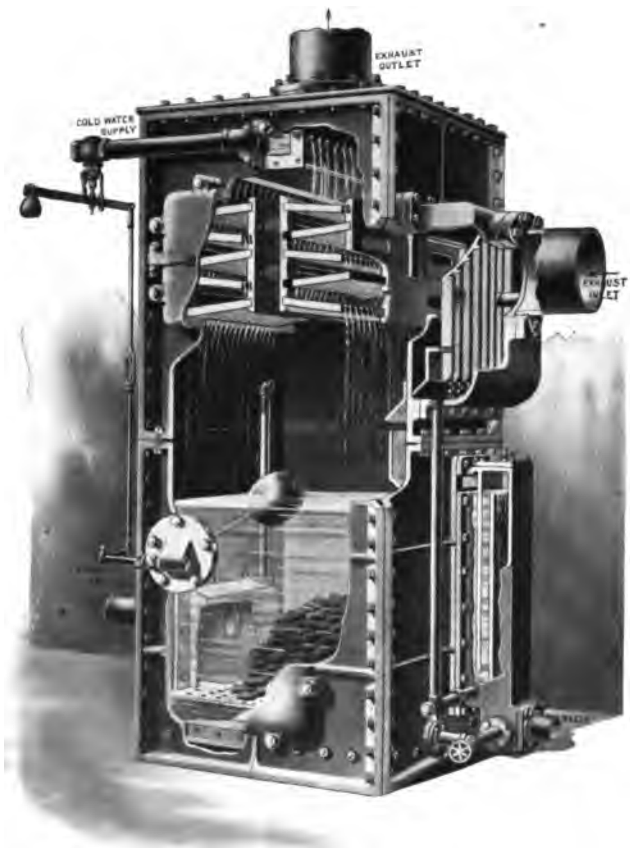


FIG 2. Cochrane Oil Separator on Cochrane Feed-Water Heater.

The illustration presented above shows a form of the Cochrane Oil Separators, *i. e.*, those used in connection with the Cochrane Feed-Water Heaters. As these Heaters are of the open type, in which the exhaust steam and the water to be heated are brought into direct or actual contact, their success depends primarily upon the efficiency of this Oil Separator.

The advantage of the closed heater over that of the open type is that the feed water can be pumped through it, thus the pump handles cold water, whereas with the open heater the pumps have to be specially fitted for hot water. Closed heaters have

to be provided with drains and mud blow-offs, the drains to take away water of condensation and oil extracted from the exhaust steam, the mud blow-offs for removing the settlings from the feed water.

All heaters, either open or closed, should be by-passed with sufficient valves, that is, provision should be made so that the exhaust steam may pass through these heaters or directly to the atmosphere. The heaters may also be provided with vent pipes connected to the atmospheric exhaust pipe to carry away air and vapor.

As already stated there are steam-tube and water-tube, closed feed-water heaters; the former type is shown in Fig. 4, which represents the Otis. An arrangement of water tube heaters is shown in Fig. 6. In this cut two feed-water heaters are connected to the exhaust from the prime mover and that of the auxiliary machines. This arrangement is possible in small installations only, and will operate very economically.

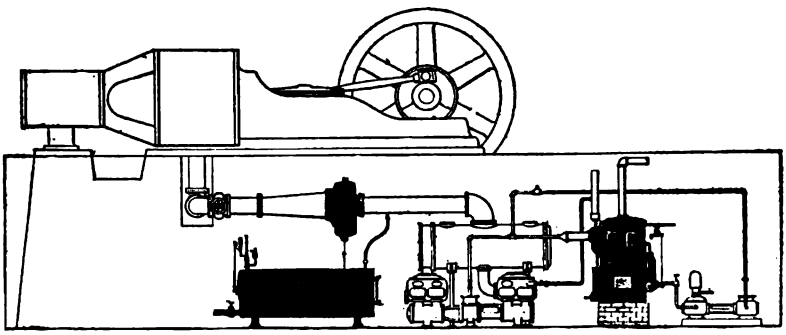


FIG. 3. Arrangement of Cochrane Feed-Water Heater and Vacuum Oil Separator.

The boiler feed water is first brought to a heater, which is located between the engines and the condenser, the water may be heated up to 120° Fahr. if 26 inches vacuum is maintained at the condenser. This 26 inches vacuum does not extend all the way back to the engine, as the loss due to friction may amount to several inches, depending on the design of the plant. From here the boiler feed water passes to the auxiliary heater, which receives exhaust steam from the various pumps, raising the water to 210° Fahr. A considerable amount of condensing water may be saved by this arrangement.

Economizer. — The location of the economizer depends upon the design of the plant, whether the smoke flue is underground or overhead. In the former case the apparatus would be located in the basement, as in the twin municipal light and power plants at Vienna, while in the latter case a special floor is required, as has been done in the St. Denis plant at Paris. Very frequently the economizer is placed directly in rear of the boiler, as has been done in the Chelsea plant of London.

The economizer should be placed as close as possible to the boilers, so that it will receive the hot gases before they cool. The flue connection to the economizer should be provided with a by-pass, so that repairs can be made without shutting down. Fig. 7

represents a layout of the Green economizer at the power plant of the Union Railroad Company, at Providence, R.I.; the system of by-passing may readily be seen.

FIG. 4. Otis closed Feed-Water Heater.

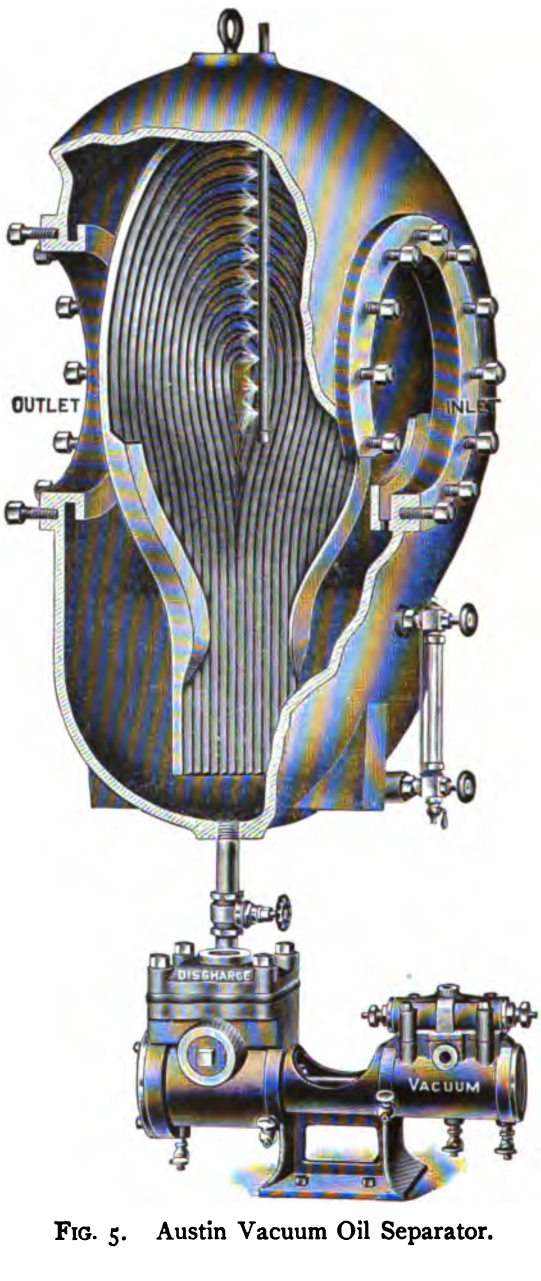


FIG. 5. Austin Vacuum Oil Separator.

Economizers are made of a number of tubes arranged in rows, either parallel or staggered, through which the water circulates. They are usually made of the counter-current type, that is, the hottest gas comes in contact with the hottest water and *vice*

versa. As soot will collect on a cool surface very readily, scrapers are arranged on each tube to remove this deposit as fast as it may accumulate. These scrapers are

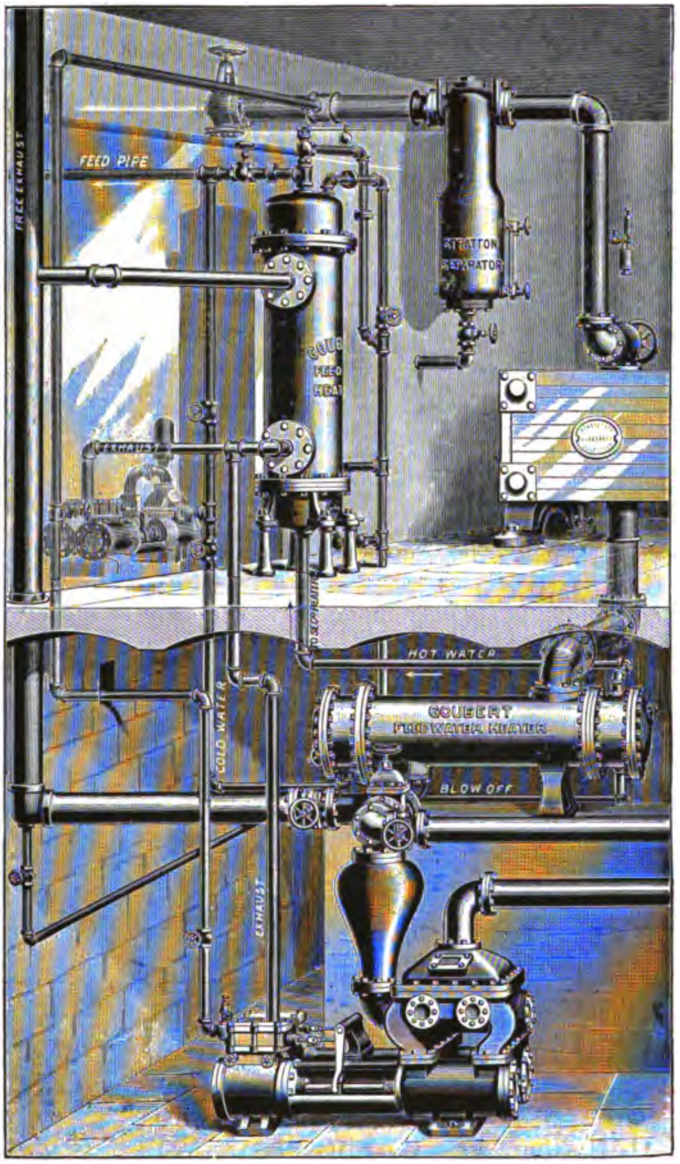


Fig. 6. Arrangement of Primary and Supplementary Heaters in connection with Condensing Engine.

operated in groups by a reversing gear, which causes them to travel continuously up and down the tube.

Owing to the friction of the gas in the economizer, and also to the low temperature

to which the gases may be reduced, the height of the chimney has to be increased from 20 to 30 per cent over that where no economizer is employed. In order to overcome

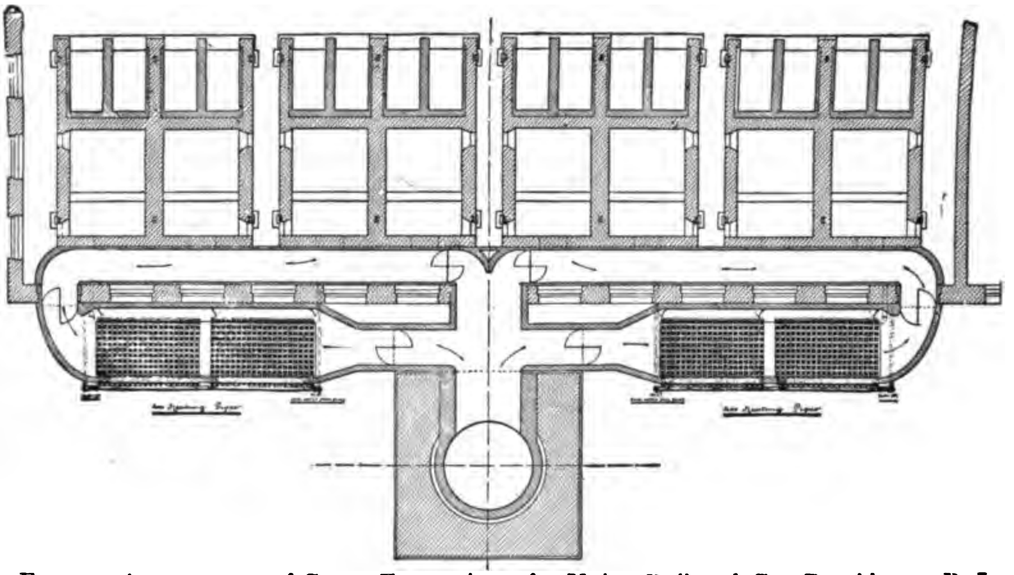


Fig. 7. Arrangement of Green Economizers for Union Railroad Co., Providence, R. I.

this, mechanical draft may be installed, and at the same time the stack temperature may be reduced to 300° Fahr. instead of 450° to 500° Fahr., as required for natural chimney draft.

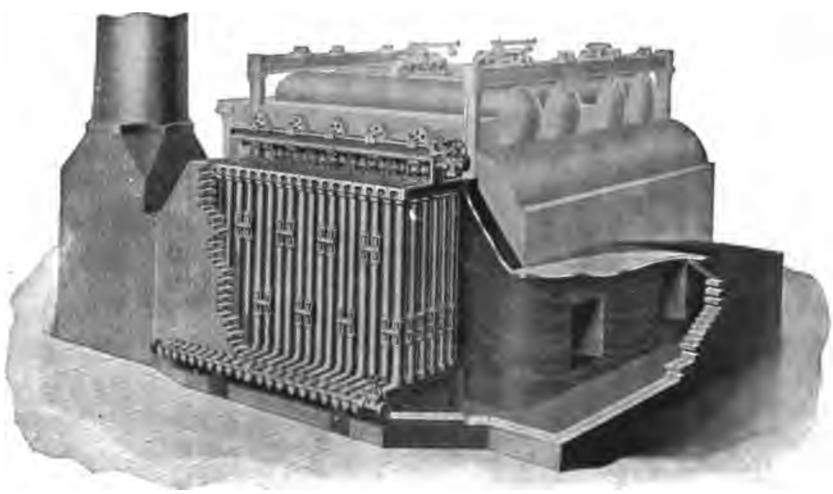


Fig. 8. Green Economizer.

Percentage of Gain. — Should exhaust steam be available, the latent heat should be utilized to heat the boiler feed water, either in an open or closed heater, or in a

TABLE I. PERCENTAGE OF SAVING FOR EACH DEGREE OF INCREASE IN TEMPERATURE OF FEED-WATER HEATED.

	Pressure of Steam in Boiler, lbs. per sq in. above Atmosphere.											
Initial Temp. of Feed.	0	20	40	60	80	100	120	140	160	180	200	Initial Temp.
32°	.0872	.0861	.0855	.0851	.0847	.0844	.0841	.0839	.0837	.0835	.0833	32°
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0811	.0839	40
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846	50
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853	60
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860	70
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868	80
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875	90
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883	100
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891	110
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899	120
130	.0954	.0941	.0934	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907	130
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916	140
150	.0973	0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924	150
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933	160
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941	170
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951	180
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960	190
200	.1022	.1008	.0990	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969	200
210	.1033	.1018	.1009	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979	210
220		.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989	220
230		.1039	.1031	.1024	.1018	.1012	.1010	.1007	.1003	.1001	.0999	230
240		.1050	.1041	.1034	.1029	.1024	.1020	.1017	.1014	.1011	.1009	240
250		.1063	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019	250

storage tank, provided with coils, whence the water may be pumped through the economizer, thus not only removing certain stresses from the economizer, but also improving the efficiency of the plant. The efficiency of an economizer is frequently claimed to

TABLE II. PERCENTAGE OF SAVING EFFECTED BY HEATING FEED-WATER FROM INITIAL TO FINAL TEMPERATURE.

BOILER GAUGE PRESSURE 100 POUNDS

INITIAL TEMPERATURE	FINAL TEMPERATURE OF WATER															
	100	120	140	160	180	200	210	220	230	240	250	260	270	280	290	300
60	3.5	5.2	6.9	8.6	10.4	12.1	13.0	13.8	14.7	15.5	16.4	17.3	18.1	19.0	19.8	20.7
80	1.7	3.5	5.2	7.0	8.8	10.5	11.4	12.3	13.2	14.0	14.9	15.8	16.7	17.5	18.4	19.3
100	0	1.8	3.6	5.4	7.1	8.9	9.8	10.7	11.6	12.5	13.4	14.3	15.2	16.1	17.0	17.9
110		0.9	2.7	4.5	6.3	8.1	9.0	9.9	10.8	11.7	12.6	13.5	14.4	15.3	16.2	17.1
120		0	1.8	3.6	5.5	7.3	8.2	9.1	10.0	10.9	11.8	12.7	13.6	14.5	15.5	16.4
130			0.9	2.8	4.6	6.9	7.4	8.3	9.2	10.1	11.0	11.9	12.8	13.8	14.7	15.6
140			0	1.9	3.7	5.6	6.5	7.4	8.4	9.3	10.2	11.1	12.1	13.0	13.9	14.9
150				0.9	2.8	4.7	5.6	6.6	7.5	8.4	9.4	10.3	11.2	12.2	13.1	14.0
160				0	1.9	3.8	4.7	5.7	6.6	7.6	8.5	9.5	10.4	11.4	12.3	13.2
170					1.0	2.9	3.8	4.8	5.7	6.7	7.6	8.6	9.5	10.5	11.5	12.4
180					0	1.9	2.9	3.9	4.8	5.8	6.8	7.7	8.7	9.7	10.6	11.6
190						1.0	1.9	2.9	3.9	4.9	5.8	6.8	7.8	8.8	9.7	10.7
200						0	1.0	2.0	3.0	3.9	4.9	5.9	6.9	7.9	8.9	9.8
205							0.5	1.5	2.5	3.5	4.9	5.4	4.0	4.5	4.9	6.4
210							0	.5	1.0	2.0	3 0	4.0	5.0	6.0	7.0	8.0

be from 10 to 20 per cent according to the temperature of the gas escaping from the boilers. In many instances it has been proven that with an economizer boiler feed water has been obtained up to 250° Fahr. The percentage of gain resulting from the

increase of temperature of the feed water, either in an economizer or heater in any particular case, can be easily calculated by the following formula:

$$\text{Gain per cent} = \frac{100\,(T - t)}{H - t}.$$

Where H = total heat of steam at boiler pressure reckoned from 0° Fahr.
T = temperature of feed water after heating.
t = temperature of feed water before heating.

It will be seen from this that the higher the exhaust steam or flue temperature to be utilized, the greater is the gain.

The preceding table I, gives the percentage of saving for each degree of increase in temperature of feed water heated, calculated with the above formula.

SUPERHEATERS.

Classification. — In order to produce superheated steam, additional heat must be applied to dry steam. This may be accomplished by installing a special apparatus, either in the boiler setting or in a separate setting having its own furnace. A number of small superheaters installed in each individual boiler are, of course, more expensive, as regards first cost, than a few large superheaters in separate settings. It is, however, difficult to install a separately fired superheater, owing to the arrangement of the boiler room, and the difficulty of handling coal and ashes; besides this the pipe connections are more complicated. An advantage of the separately fired superheater is that it may be placed close to the prime mover, decreasing the loss of heat in the piping. The temperature may be equally controlled in each type. With the use of "boiler setting or flue superheaters" no additional space is required, the operating force will be reduced, as the stokers attend to the boiler and superheater, and the pipe connections are simplified.

The superheater itself, as will be seen later, may be classified in two types, namely, a fire-tube heater, similar to a tubular boiler, where the gases of combustion pass through tubes surrounded by steam, and a steam-tube type, where steam passes through the tubes surrounded by hot gases; these superheaters may again be subclassified as cast-iron and steel-tube type.

Material. — Cast iron is not used to any great extent in the construction of superheaters, although there have been many introduced; the difference in temperature of the steam in the tubes and the flue gases causes their quick destruction.

One type of cast-iron superheater, the Schwoerer, however, has met with success; it is made of some secret alloy of cast iron. This type of superheater was one of the earliest and is largely used in the southern part of Germany and Austria. Ernst, in a report to the "Engineering Congress of the International Society of Boiler Inspectors," at Zürich in 1902, states that in the district of the Vienna Boiler Inspection and Insur-

ance Society, which included 599 power plants, equipped with superheaters, 20.2 per cent were of cast iron, while 99 per cent of these were of the Schwoerer type; 14 per cent of the 599 were of the separately fired type.

In the northern part of Germany steel superheaters are in use exclusively; one report shows that in nine boiler inspection districts not a single cast-iron apparatus was employed. It will be easily understood that common cast iron cannot withstand the differences in temperature; for instance, Ripper reports in the Minutes of Proceedings of the Institute of Civil Engineers that with a steam temperature of 340° Fahr., the pipe shell temperature was 610°, or a difference of 270° Fahr. As this test was made on a wrought-iron superheater, the difference of temperature in a cast-iron superheater will be still greater. Besides this in modern power plant practice, with the production of temperature from 650° to 750° Fahr., the difference in temperature will be greatly increased.

There is, however, a great advantage in a cast-iron superheater, provided that the alloy is a proper one. As this type of superheater is made up of extended surface and the material is correspondingly heavy, the shell stores a greater amount of heat than a steel type superheater and is, therefore, not so readily affected by the cold draft when opening fire doors, and a more even temperature of steam is obtained. This type of superheater may be used with equal advantage, either with a hand-fired or mechanical stoker furnace.

Steel superheaters are much more readily adaptable to the available space in the boiler setting, and a greater heating surface may be obtained in a smaller space than with one of cast-iron type. The steel superheater is also cheaper and easier to repair, as there are no special parts and any machine shop may do the work. As a light steel shell is very sensitive to change in temperature, the thickness of the walls of the tubes should be heavier than the pressure requires, to add to the durability and economy of the superheater. For this purpose nickel-steel tubes have been introduced, but owing to high first cost they have not been favored.

Cross-Section. — In order to keep the steam as near the hot gases as possible, the tubes are made either small, with extended surface, or with an inner tube. The accompanying illustration, Fig. 1, shows a number of styles of tubes, both of cast iron and of steel. The upper left-hand illustration shows the Schwoerer type, these tubes have an internal diameter of $7\frac{1}{2}$ inches. They are provided with ribs both inside and outside, the inside ribs running longitudinally and the outside radially, thus forming a large absorbing surface as well as a large radiating surface. The other two upper illustrations also show cast-iron tubes, the first with a straight division wall running through the center of the tube to a point near the end, so as to create a circulation as shown by the arrows, while the second type is provided with a spiral division wall, which gives the steam a rotary motion.

The lower illustrations show superheaters of various types made of steel or similar material, the first one being a simple tube of from $1\frac{1}{2}$ inches to 3 inches in diameter; this is the one most commonly used. The thickness of these tubes varies from $\frac{1}{8}$ inch

to ½ inch. The next illustration represents the Adorjan tube, which is 4½ inches outside diameter. In order to reduce the cubical contents an inner tube is inserted, this inner tube contains still air. This design is practically the same as that of the Foster, with the exception that, in the case of the latter, the inner tube is larger, giving less cubical contents and a higher temperature with the same amount of heating surface; the outer surface is extended similarly to the Schwoerer type.

The next represents the Cruse controllable superheater. The outside diameter of the large tube is 6 inches, while the inner tube is 2 inches. This inner tube contains water (boiler feed) instead of air, as in the former types. The principal object of this

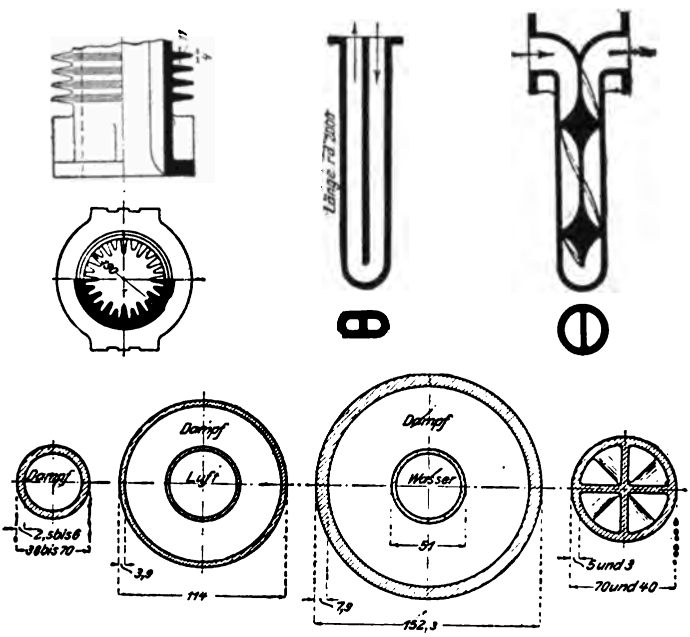


FIG. 1. Sections of Superheater Tubes.

type of superheater is to control the amount of superheat by means of the boiler feed water. If, for instance, a small amount of steam be used and the liability arises of the superheater becoming overheated, the circulation of water is increased.

The last illustration shows a very efficient type of superheater tube, which is made in two different sizes, viz., 1½ inches and 2¾ inches diameter. These tubes are made in the boiler works of B. Meyer in Gleitwitz, Germany. It consists of a steel spiral cross rolled in a plain steel tube. These spiral crosses not only give the steam a high rotation, but also increase the radiating surface 55 per cent. The crosses are set at one complete turn per meter (3.28 feet). As these crosses are not inserted in the bends, the steam will revolve thirty to forty revolutions per minute. The efficiency of these tubes is from 40 per cent to 50 per cent higher than a straight tube. Its disadvantage is the high cost of manufacture. This apparatus is especially adaptable to a boiler

where but a limited space can be given to the superheater, and where a high degree of superheat is desired.

Circulation of Steam and Flow of Gases. — The circulation of steam in a superheater varies with the design, as is indicated in Fig. 2. The form varies from straight

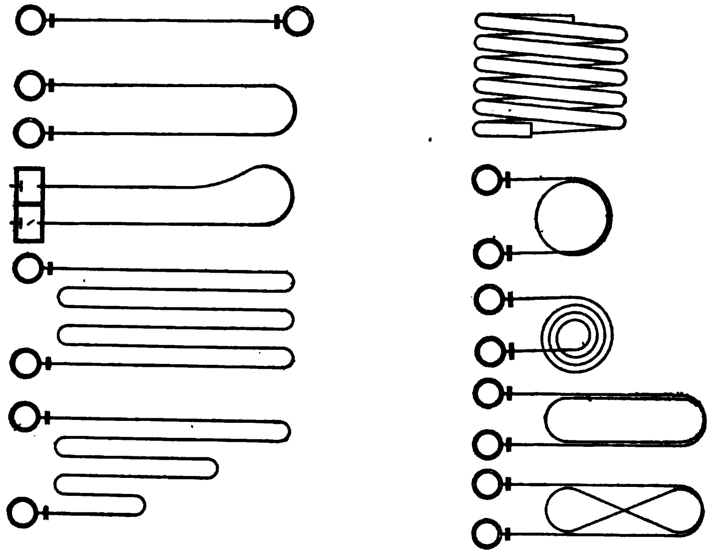


FIG. 2. Forms of Superheaters.

pipe to multiple return bends and spiral coils. Whatever type of superheater may be adopted, care should be taken that there are no rigid connections, so that expansion will be easily provided for; further, that the tubes contain no water pockets. Where, however, such conditions exist, proper drains should be installed. The apparatus should be designed and placed so that the collection of soot will be minimized, as soot will greatly decrease the efficiency. Soot is a very poor conductor, and the experiments made by Ernst show that one square meter (10.7 square feet) transmitting per hour 3,000 calories (1,191,000 B.T.U.) will require in addition 46° C. (115° Fahr.) if one millimeter ($\frac{1}{25}$ inch) of soot covers the pipes of the superheater. Therefore the superheater should be so located that it is readily accessible, so that it may be cleaned at frequent intervals. This is doubly important with such types of superheaters as will collect and hold a large amount of soot.

The superheater should be designed and located in the boiler so that it will absorb the greatest amount of heat. The tubes should be staggered.

As shown in the accompanying illustration, Fig. 3, there are three systems, parallel current, counter current and a combination of same. The first illustration represents a parallel current, while the second one represents a counter current; it will be observed that in the latter case the hottest gas comes in contact with the hottest steam, thus

materially increasing the efficiency of the apparatus. The theoretical efficiency of the former to the latter is as 1:1.158.

Owing to the fact that the delivery temperature of the steam in the counter-current type is at times too high and is subject to fluctuation, a combination of these two types is used. This is shown in the following two illustrations, the first of which is parallel and counter current, while the second (shown in lower left-hand corner) is counter and

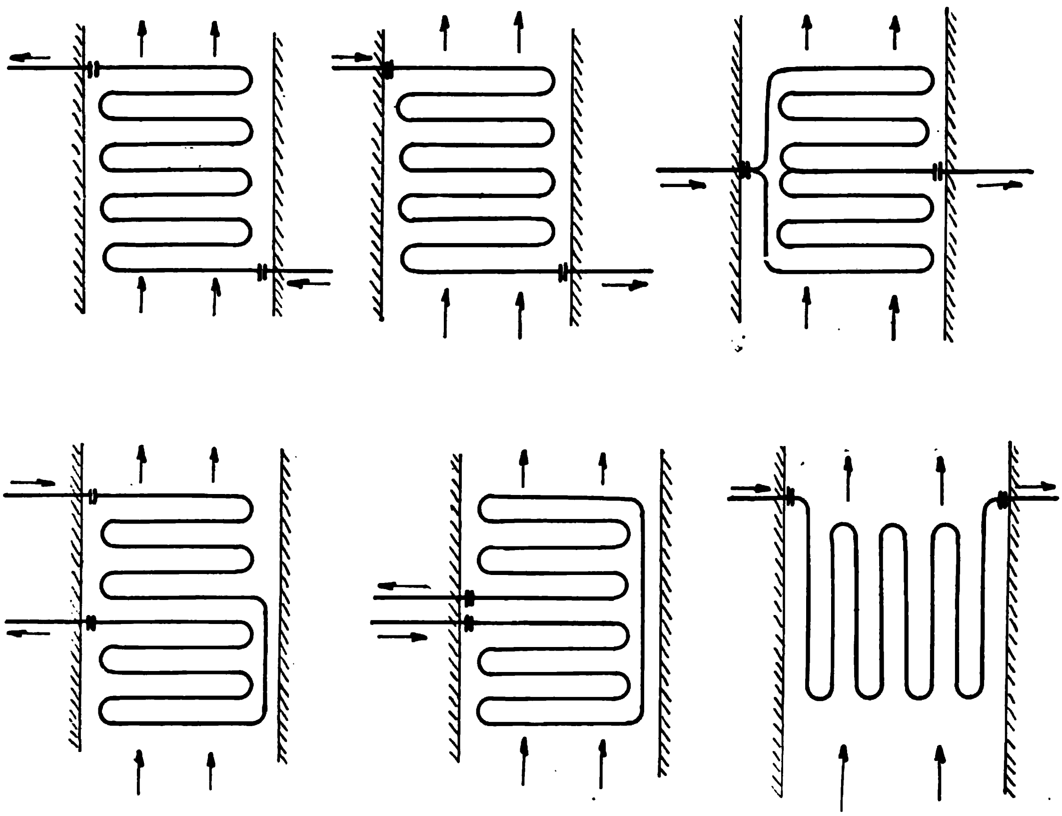


FIG. 3. Flow of Gases and Steam in Superheaters.

parallel. The next illustration shows a double counter-current type. In this type the steam first passes through the hottest gases, returning as shown and passing through the cooler gases. In all of these systems the flow of steam is at right angles to the flow of gas. Superheaters of this style are used in Europe. The last illustration is the type almost exclusively used in America and also to a large extent in Europe. This type is a counter-parallel superheater.

Controlling Temperature.—There are various devices for controlling the temperature of superheated steam; viz., regulating the amount of flue gases passing through the superheater, mixing saturated steam with superheated steam, injecting a fine spray of water into the superheated steam, or by water or air cooling.

For regulating the amount of gas passing through the superheater, butterfly dampers may be installed, so that all of the gases may pass over the superheater or only a desired percentage. Fig. 4 represents a design of this character. It will be seen that any amount of gases desired may be passed over the apparatus, or it may be cut out entirely in case the superheater breaks down, in which case the boiler could still be used, supplying saturated steam. These superheaters, which are of the Buettner type, are also installed without dampers, in which case the shell of the tubes is of heavy material, so as to stand the high temperature before steam is raised. The amount of superheat will then be controlled by mixing saturated with superheated steam.

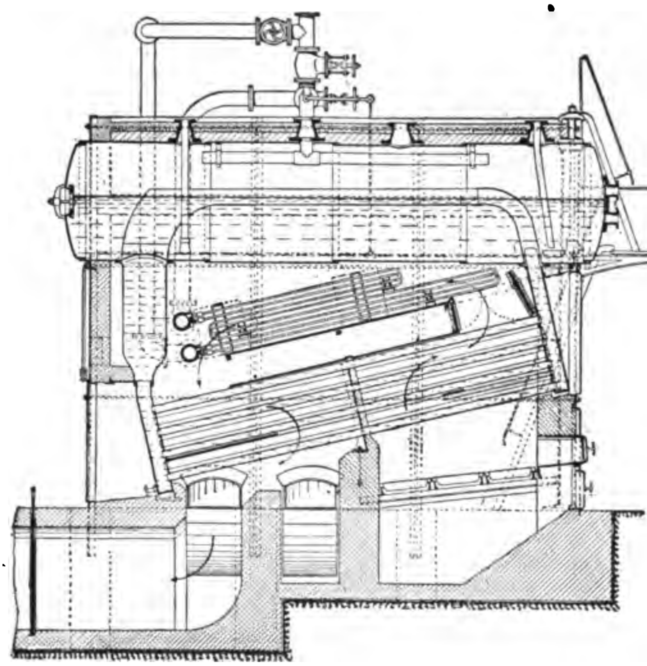


Fig. 4. Buettner Superheater.

Another system of temperature control is that given in Fig. 5, representing a separately fired superheater, which is designed and operated as follows: The tubes of the superheater are located in two chambers separated by a division wall, the furnace being in one section and the throttling damper in the other section. In the lower row of tubes, connected to the header, are inserted steam-tight tubes, which are closed at one end while the other end connects with a small separate header. These tubes are filled with air, which, with an increased temperature, operates on a small cylinder filled with glycerine, provided with a float, which in turn operates the well-balanced throttling damper, thus regulating the amount of air under the furnaces, and changing the character of the furnace gas. The massiveness of this superheater setting will also be noticed, which prevents undesirable radiation. For the same purpose both headers of this superheater are kept in a chamber apart from that conducting the furnace gas.

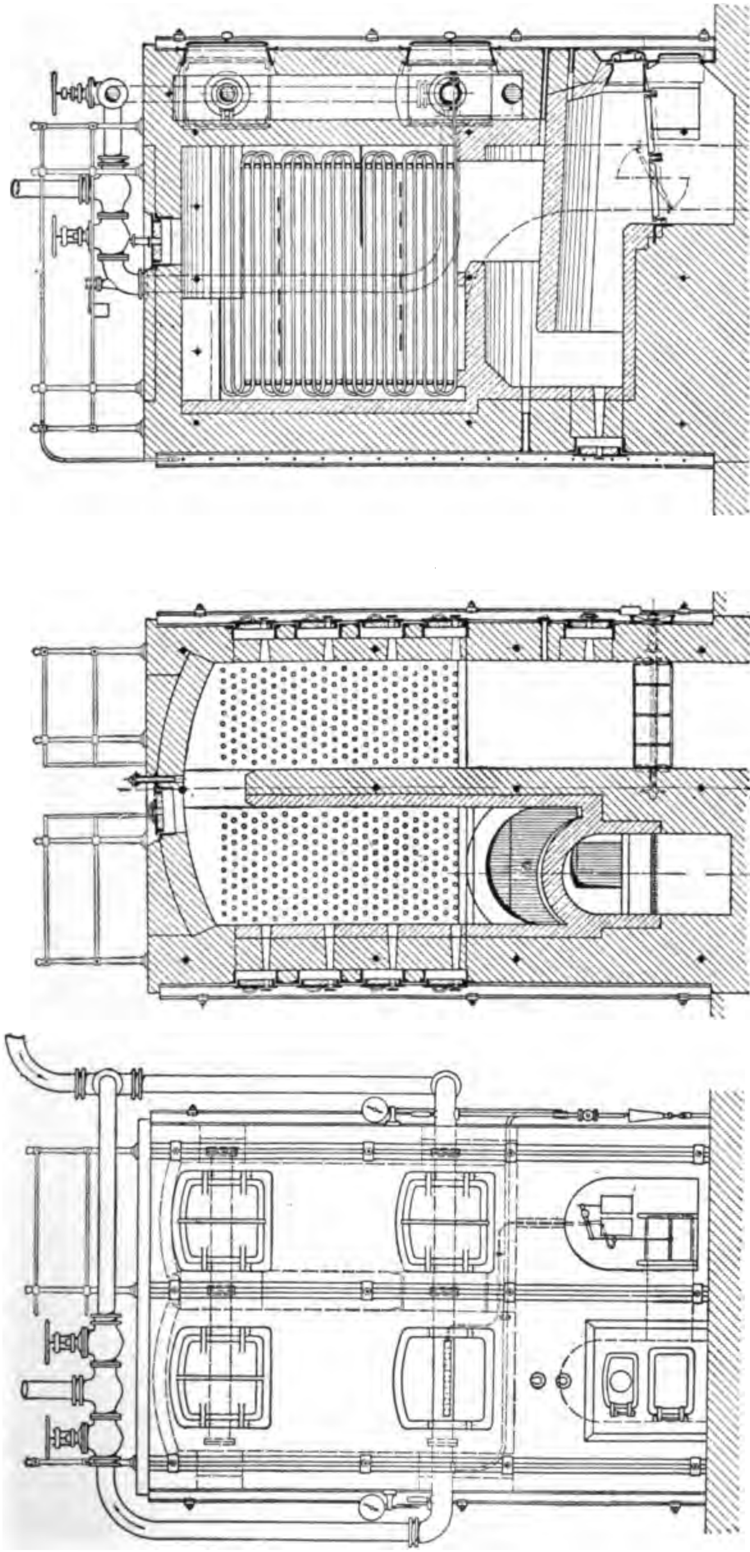


FIG. 5. Dingler Air Controlled, Separate Fired Superheater.

It will be noticed in the right-hand illustration that the furnace is constructed with a heat-storage chamber, so that the opening of the fire door, admitting cold air, will not cause a fluctuation in the temperature of the steam.

By injecting a fine spray of water into the superheated steam at a point where it leaves the superheater, any desired temperature may be obtained; but owing to the low

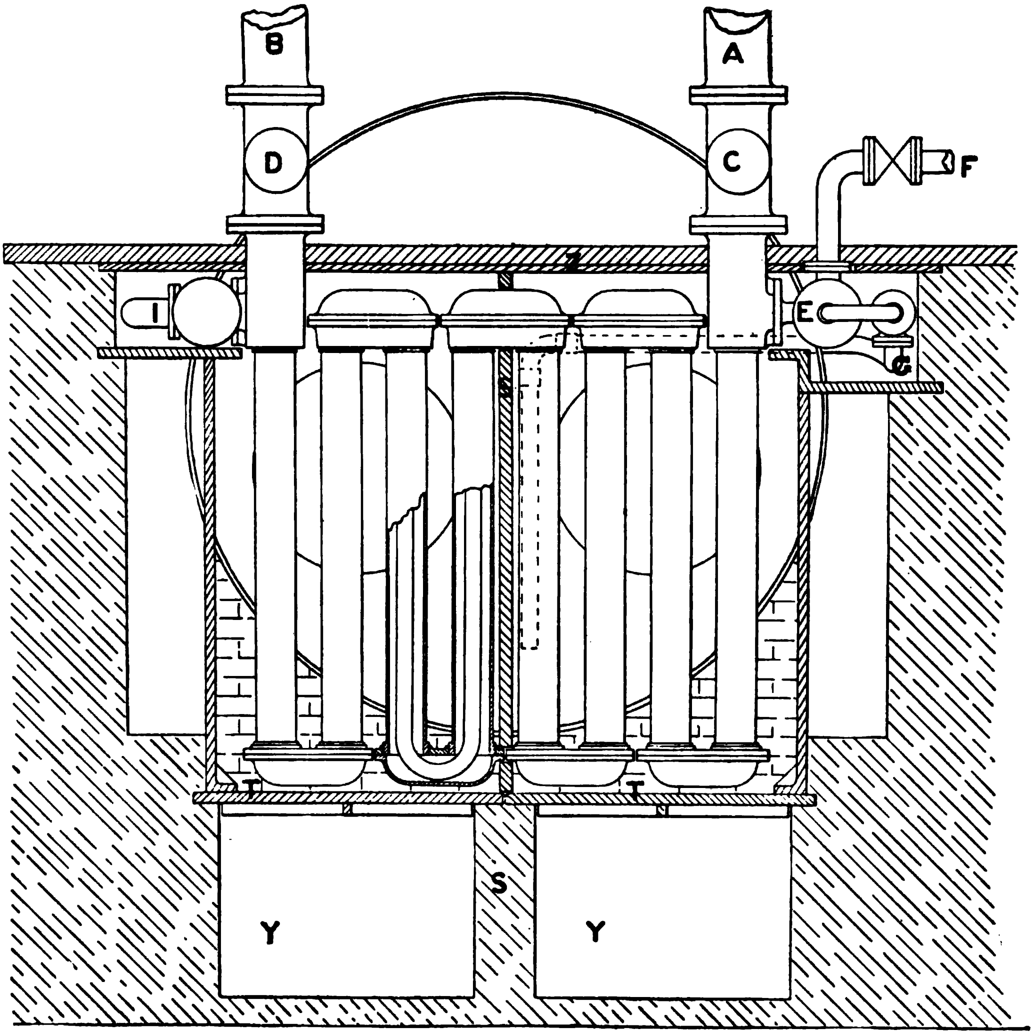


FIG. 6. Cruse Controllable Superheater.

conductivity of superheated steam the water may not be entirely evaporated and may, therefore, be carried along into the prime movers. This system of controlling the temperature is, therefore, not favored very much.

A system controlling the temperature of superheated steam by water is the Cruse, and is designed and operated as follows: a water branch is taken from the boiler at

low water level, and water is drawn out at this branch and forced through two-inch copper pipes, which traverse the superheater pipes from end to end and return to the boiler. Thus each end of this copper pipe is exposed to boiler pressure, and to force water through it only demands energy sufficient to overcome the friction, which is not great in a solid drawn copper pipe. To produce the flow the water is passed through an inspirator fed with superheated steam. When superheated steam touches water it at once becomes saturated, and, at usual temperatures of superheat, it loses say 20 per cent of its volume. This reduction of volume is, like the condensation in an ordinary injector, the source of energy, and serves to propel the water through the inner tubes at a considerable velocity. Should the gases become hotter and the steam temperature rise, its volume increases, and the action of the inspirator is correspondingly intensified. More water flows and picks up more heat from the surrounding steam. In this way the control exercised by the water columns is automatic, the result being that the temperature of superheat varies between narrow limits and the danger point is never reached. This Cruse controllable superheater is shown in the accompanying illustration, Fig. 6. The apparatus in this case is located in the rear of a flue boiler.

Instead of having water circulating through the inner tube of the superheater for the purpose of controlling the temperature, air may be circulated through same, as is done in the Adorjan superheater. This, as previously stated, is practically the same as that of the well-known Foster superheater, an illustration of which is given in the chapter on boilers, with the difference that in the latter type the air is stationary, and, therefore, not controllable. The temperature of the steam in the Foster system may be controlled by mixing saturated with superheated steam.

Velocity of Steam. — The velocity of the steam in the superheater depends entirely on the design and pressure used, and should be such as not greatly to reduce the pressure due to friction. In a superheater having small tubes the steam may travel at a higher velocity than in one having large tubes, because the heating surface is distributed more economically per unit of steam. Where steam is used at a pressure above 150 pounds a fall in the pressure of from four to five pounds is the maximum that should be allowed, while with a pressure below 150 pounds the drop should not exceed three to four pounds. In a test reported by Berner on a superheater of the counter-parallel type, as illustrated at the left hand of Fig. 3, the drop in pressure was, in the counter-current part of the superheater, 3.5 pounds, while in the parallel-current side of the superheater the drop was 2.5 pounds, making a total loss of 6 pounds. The pressure under which this test was carried on was 215 pounds, while the diameter of the tubes was $1\frac{1}{2}$ inches; the velocity in the tubes of the counter-current side was 45 feet per second, while in the parallel-current side the velocity was 66 feet per second.

Low velocities are used in certain types of "fire-tube" superheaters, amounting to from 13 to 20 feet per second. In the greater number of superheaters, velocities of from 40 to 60 feet per second are used, while in some types, for instance, the spiral cross superheater, velocities up to 90 feet per second may be employed.

Size. — There is no fixed formula that can be given for calculating the size of a superheater, as there are too many items to be taken into consideration, such as the design of the apparatus, or if counter or parallel flow, etc.

A superheater made up of small tubes and located in the setting of water-tube boilers needs a heating surface of from 10 per cent to 12 per cent of that of the boiler to secure a steam temperature (total) of from 460° to 500° Fahr.; while a heating

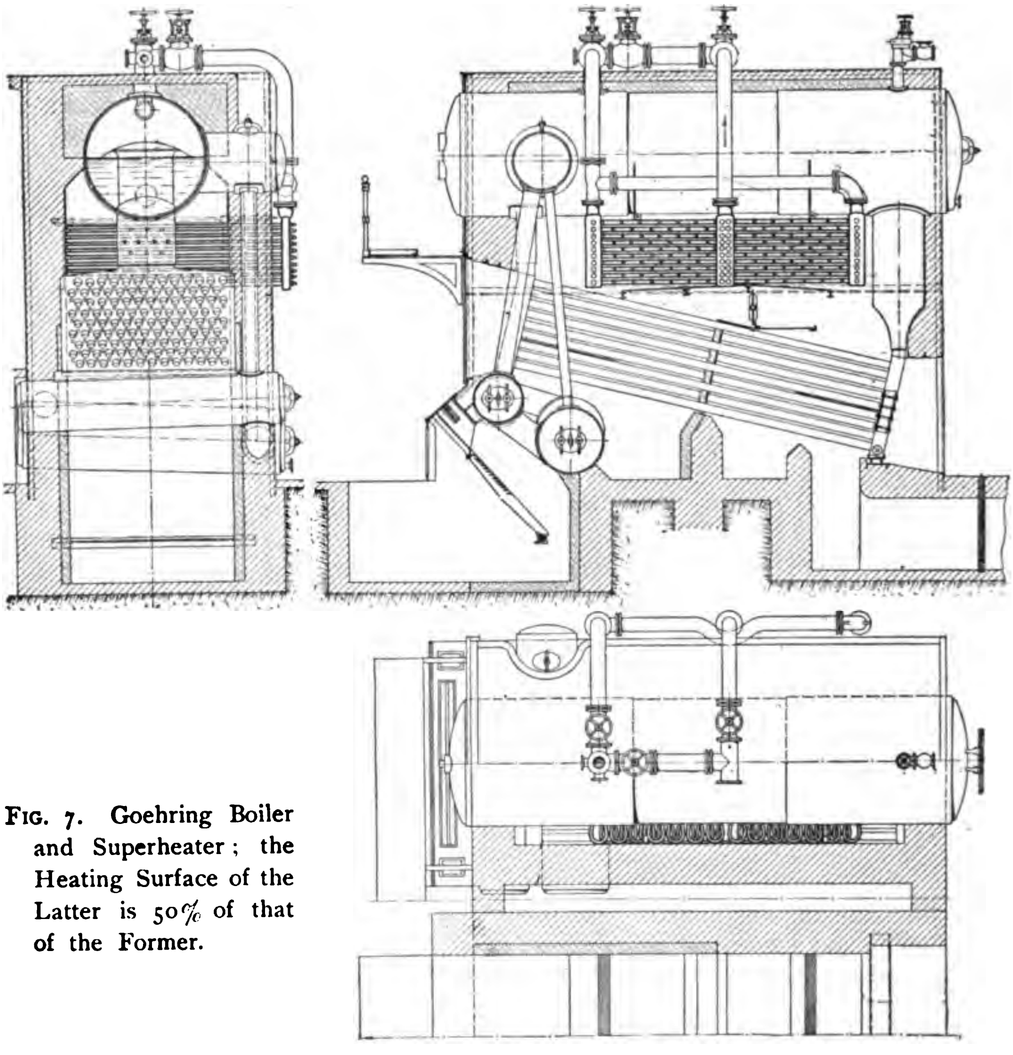


FIG. 7. Goehring Boiler and Superheater; the Heating Surface of the Latter is 50% of that of the Former.

surface of 20 per cent of that of the boilers will give a temperature of approximately 570° to 600° Fahr. If the heating surface of the superheater is one-third that of the boiler, the temperature will be about 660° Fahr. Superheaters of this size are not in use at present in America or England, but there are many in service on the Continent

of Europe, in fact there are a number which run as high as 50 per cent. The accompanying illustration, Fig. 7, shows a superheater of this size installed in a water-tube boiler; under ordinary operating conditions 750° Fahr. may be easily obtained.

All the above figures are based on practical experience, where the boiler pressure is from 175 to 225 pounds.

The amount of coal required to superheat steam varies with the design and location of the superheater and the temperatures of the steam. The specific heat of superheated steam varies with the temperature. Regnault determined the specific heat of superheated steam at atmospheric pressure to be 0.48, but more recent investigation shows that this varies, as for instance, with 100° superheat the specific heat is 0.65, while it is 0.75 for 200°.

The following table, based on the above figures and an experiment made by the Stirling Consolidated Boiler Co. with their superheater, as published by the latter in "A Book on Steam for Engineers," may be of interest:

COAL NEEDED FOR SUPERHEATING.

Degrees of Superheat.	Additional Coal Needed.
75°	5 per cent
100°	7 "
150°	11 "
200°	15 "
250°	20 "

These data are not given here to show an increased coal consumption for superheated steam, for with the use of superheated steam it is required that less water be evaporated than would be the case if saturated steam were employed. This fact more than counterbalances the amount of coal required to superheat, provided proper prime movers have been selected. For the same reason the size of the boiler may be reduced.

Types. — There are a great number of different types of superheaters on the market, some of which have been illustrated in the chapter on boilers and also in the beginning of this article. The Foster and Babcock & Wilcox superheaters have already been mentioned. The former is constructed of steel tubes, with extended surfaces formed of cast-iron rings, forming a heavy mass, which gives a large storage capacity for heat, thus reducing the fluctuation of temperature in the steam. The Babcock & Wilcox apparatus is of the small tube type, with arrangement to flood same in order to protect the tubes before steam is raised. There is a disadvantage in flooding a superheater if the water used is dirty or impure, as it will scale the tubes; these tubes cannot very well be cleaned, and they will have to be removed and replaced. If this is not done the efficiency of the superheater will be decreased.

Another type of small tube superheater is given in Fig. 8, illustrating the Watkinson system. This superheater, as illustrated, is not separately fired, but is separately set, being located in the boiler flue path. Arrangement may be made to by-pass, so

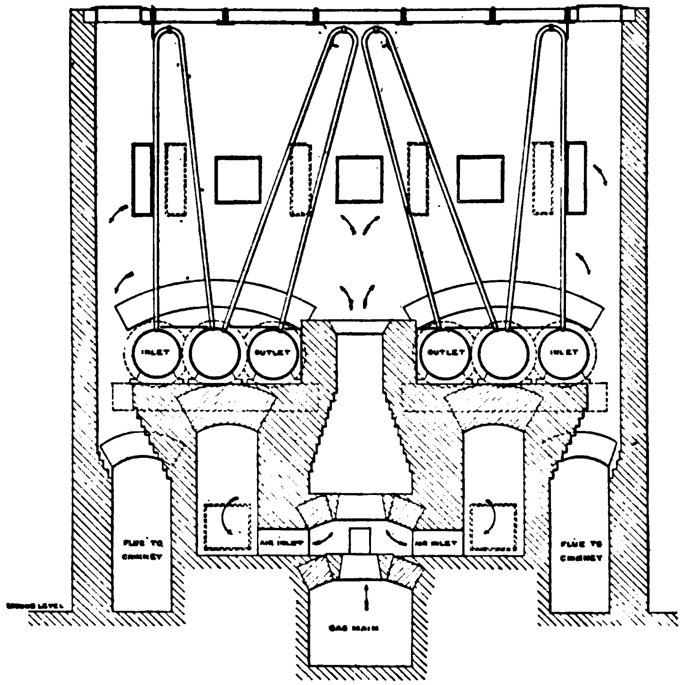


FIG. 8. Watkinson Superheater.

that any amount of gas may be sent through the setting or it may be cut out entirely. This same superheater may be separately fired or arranged in the boiler setting.

A cast-iron superheater which is successfully used on the Continent of Europe is the Schwoerer, shown in Fig. 9. In this particular case the superheater is separately fired and consists of fourteen tubes. As the tubes are vertical, provision is made to drain each tube.

A fire-tube superheater is shown in Fig. 10. This type of construction is new, although its principle rests upon one of the earlier superheater systems, namely, a long cylindrical chamber, in which were inserted tubes conveying the steam, while the hot gases surround them in the chamber. This newer type (Heizmann), as will be seen, is a flat box, of only $1\frac{1}{2}$ inches thickness over all, through which two-inch tubes are passed in staggered rows, expanded into the sides; while the hot furnace gases pass through these tubes, the steam in passing through the box is deflected at as many points as there are tubes, thus thoroughly mixing it and producing a uniformly high temperature.

A similar system is that of Prégardien. In this system, instead of having the box riveted together and the pipes inserted, the entire apparatus is welded together as

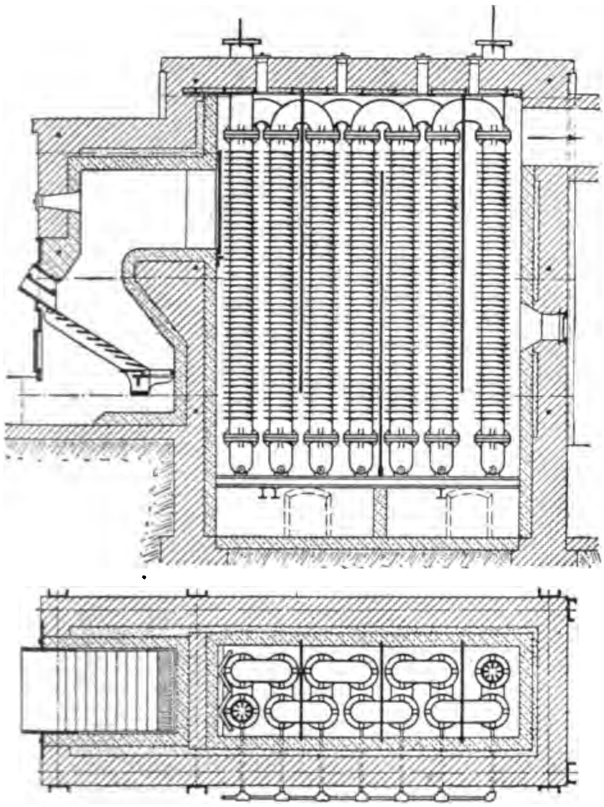


FIG. 9. Schwoerer Separate Fired Superheater.

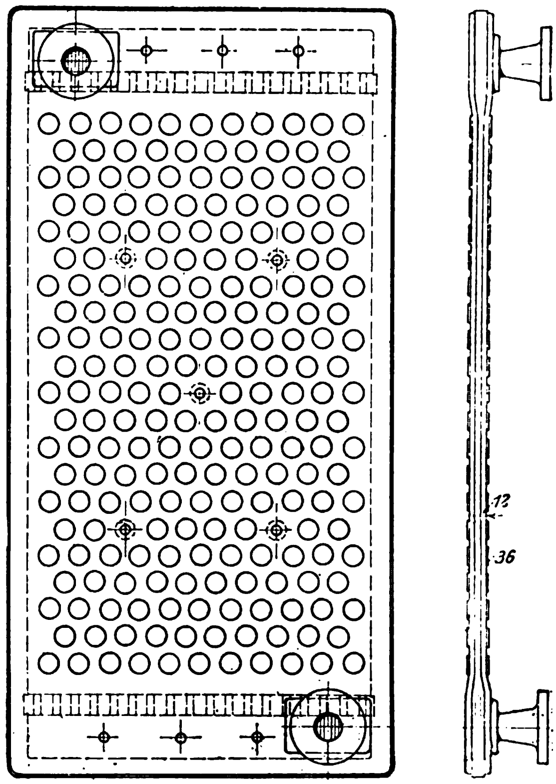


FIG. 10. Heizmann Fire Tube Superheater.

though made of a single piece. An advantage of this type of superheater is that a very high temperature may be obtained. They may be used in the boiler setting or separate fired type.

SUPERHEATED STEAM.

Saturated Steam.—Steam may be classified as live and exhaust steam; the former, which will be considered under this heading, may be sub-classified as saturated and superheated steam. Saturated steam is steam at the temperature of the boiling point of water whose temperature depends on the pressure. Saturated steam may be either wet or dry. The former is steam carrying water in suspension in the form of a mist, while the latter (dry steam) is steam containing no free moisture.

Practically all boilers, when not equipped with a special device, deliver wet saturated steam. Zeuner states that the amount of water carried over in suspension with the steam is from $7\frac{1}{2}$ per cent to 15 per cent, while Hirn, from a very satisfactory test,

found but 5 per cent. Experiments conducted on various Babcock & Wilcox boilers showed an average moisture of 8.2 per cent.

The properties of saturated and superheated steam are frequently required in calculating sizes of pipes, etc. In the following table the specific heat of superheated steam has been taken as 0.55.

Superheated Steam. — In order to produce superheated steam additional heat must be added to dry saturated steam; the temperature and volume will be increased

TABLE I. PROPERTIES OF SATURATED AND SUPERHEATED STEAM.

(From "Steam," Babcock & Wilcox Ltd., London.)

Properties of Saturated Steam. Partly from C. H. Peabody's Tables.								Total Heat of Superheated Steam from Water at 32° F (Specific heat, 0.55 B.T.U.)					
Pressure in pounds per sq. in. above vacuum.	Temperature in degrees Fahrenheit.	Total heat in heat units from water at 32°.	Heat in liquid from 32° in units.	Heat of vaporization, or latent heat in heat units.	Density or weight of cubic ft. in pounds.	Volume of one pound in cubic ft.	Factor of equivalent evaporation at 212°.	Superheat in degrees Fahrenheit. 120°	150°	200°	250°	300°	Pressure in pounds per square in. as shown by steam gauge.
1	101.99	1113.1	70.0	1043.0	0.00299	334.5	.9661	1179.1	1195.6	1223.1	1250.6	1278.1	—
2	126.27	1120.5	94.4	1026.1	0.00576	173.6	.9738	1186.5	1203.0	1230.5	1258.0	1285.5	—
3	141.62	1125.1	109.8	1015.3	0.00844	118.5	.9786	1191.1	1207.6	1235.1	1262.6	1290.1	—
4	153.09	1128.6	121.4	1007.2	0.01107	90.33	.9822	1194.6	1211.1	1238.6	1266.1	1293.6	—
5	162.34	1131.5	130.7	1000.8	0.01366	73.81	.9852	1197.5	1214.0	1241.5	1269.0	1296.5	—
6	170.14	1133.8	138.6	995.2	0.01622	61.65	.9876	1199.8	1216.3	1243.8	1271.3	1208.8	—
7	176.90	1135.9	145.4	990.5	0.01874	53.39	.9897	1201.9	1218.4	1245.9	1273.4	1300.9	—
8	182.92	1137.7	151.5	986.2	0.02125	47.06	.9916	1203.7	1220.2	1247.7	1275.2	1302.7	—
9	188.33	1139.4	156.9	982.5	0.02374	42.12	.9934	1205.4	1221.9	1249.4	1276.9	1304.4	—
10	193.25	1140.9	161.9	979.0	0.02621	38.15	.9949	1206.9	1223.4	1250.9	1278.4	1305.9	—
15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003	1212.9	1229.4	1256.9	1284.4	1311.9	1
20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051	1217.5	1234.0	1261.5	1289.0	1316.5	5
25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099	1221.1	1237.6	1265.1	1292.6	1320.1	10
30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129	1224.3	1240.8	1268.3	1295.8	1323.3	15
35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157	1227.0	1243.5	1271.0	1298.5	1326.0	20
40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182	1229.4	1245.9	1273.4	1300.9	1328.4	25
45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205	1231.6	1248.1	1275.6	1303.0	1330.6	30
50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225	1233.6	1250.1	1277.6	1305.1	1332.6	35
55	286.89	1169.4	256.3	913.1	0.1299	7.698	1.0245	1235.4	1251.9	1279.4	1306.9	1334.4	40
60	292.51	1171.2	261.9	909.3	0.1409	7.097	1.0263	1237.2	1253.7	1281.2	1308.7	1336.2	45
65	297.77	1172.7	267.2	905.5	0.1519	6.583	1.0280	1238.7	1255.2	1282.7	1310.2	1337.7	50
70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295	1240.3	1256.8	1284.3	1311.8	1339.3	55
75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309	1241.7	1258.2	1285.7	1313.2	1340.7	60
80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323	1243.0	1259.5	1287.0	1314.5	1342.0	65
85	316.02	1178.3	285.8	892.5	0.1951	5.126	1.0337	1244.3	1260.8	1288.3	1315.8	1343.3	70
90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350	1245.6	1262.1	1289.6	1317.1	1344.6	75
95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362	1246.7	1263.2	1280.7	1318.2	1345.7	80
100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374	1247.9	1264.4	1291.9	1319.4	1346.9	85
105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385	1248.9	1265.4	1292.9	1320.4	1347.9	90
110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396	1250.0	1266.5	1294.0	1321.5	1349.0	95
115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406	1251.0	1267.5	1295.0	1322.5	1350.0	100
120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416	1252.0	1268.5	1296.0	1323.5	1351.0	105
125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426	1252.6	1269.1	1296.6	1324.1	1351.6	110
130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435	1253.8	1270.3	1297.8	1325.3	1352.8	115
140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453	1255.5	1272.0	1299.5	1327.0	1354.5	125
150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470	1257.2	1273.7	1301.2	1328.7	1356.2	135
160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486	1258.8	1275.3	1302.8	1330.3	1357.8	145
170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502	1260.3	1276.8	1304.3	1331.8	1359.3	155
180	372.97	1195.7	345.4	850.3	0.3945	2.535	1.0517	1261.7	1278.2	1305.7	1333.2	1360.7	165
190	377.44	1197.1	350.1	847.0	0.4153	2.408	1.0531	1263.1	1279.6	1307.1	1334.6	1362.1	175
200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545	1264.4	1280.9	1308.4	1335.9	1363.4	185
225	391.79	1201.4	365.1	836.3	0.4876	2.051	1.0576	1267.4	1283.9	1311.4	1338.9	1366.4	210
250	400.99	1204.2	374.7	829.5	0.5393	1.854	1.0605	1270.2	1286.7	1314.2	1341.7	1369.2	235
275	409.50	1206.8	383.6	823.2	0.5913	1.691	1.0632	1272.8	1289.3	1316.8	1344.3	1371.8	260
300	417.42	1209.3	391.9	817.4	0.644	1.553	1.0657	1275.3	1291.8	1319.3	1346.8	1374.3	285
325	424.82	1211.5	399.6	811.9	0.696	1.437	1.0680	1277.5	1294.0	1321.5	1349.0	1376.5	310
350	431.90	1213.7	406.9	806.8	0.748	1.337	1.0703	1279.7	1296.2	1323.7	1351.2	1378.7	335
375	438.40	1215.7	414.2	801.5	0.800	1.250	1.0724	1281.7	1298.2	1325.7	1353.2	1380.7	360
400	445.15	1217.7	421.4	796.3	0.853	1.172	1.0745	1283.7	1300.2	1327.7	1355.2	1382.7	385
500	466.57	1224.2	444.3	779.9	1.065	.939	1.0812	1290.2	1306.7	1334.2	1361.7	1389.2	485

without varying the pressure. There is no fixed formula to-day to determine the relation of the increase in volume to the increase in temperature. For practical use the

Zeuner formula, although not absolutely accurate, is used in Europe and found fairly satisfactory.

It is as follows:

$$P_1v_1 = R\ (t_1 - 273) - Cp_1n$$

in which

p_1 = Pressure of steam in kg. per sq. cm. absolute (14.7 lbs. per sq. in.).
t_1 = Temperature of superheat (Centigrade).
v_1 = Additional volume in cubic meters.

R, C and n are constants, which for p are expressed in kilogram per square centimeter and for v in cubic meters.

$$R = 0.00509 \qquad C = 0.193 \qquad n = \tfrac{1}{4}$$

The accompanying curve chart, Fig. 1, has been plotted from the above formula and converted into the English system. From this chart it is easy to calculate the size

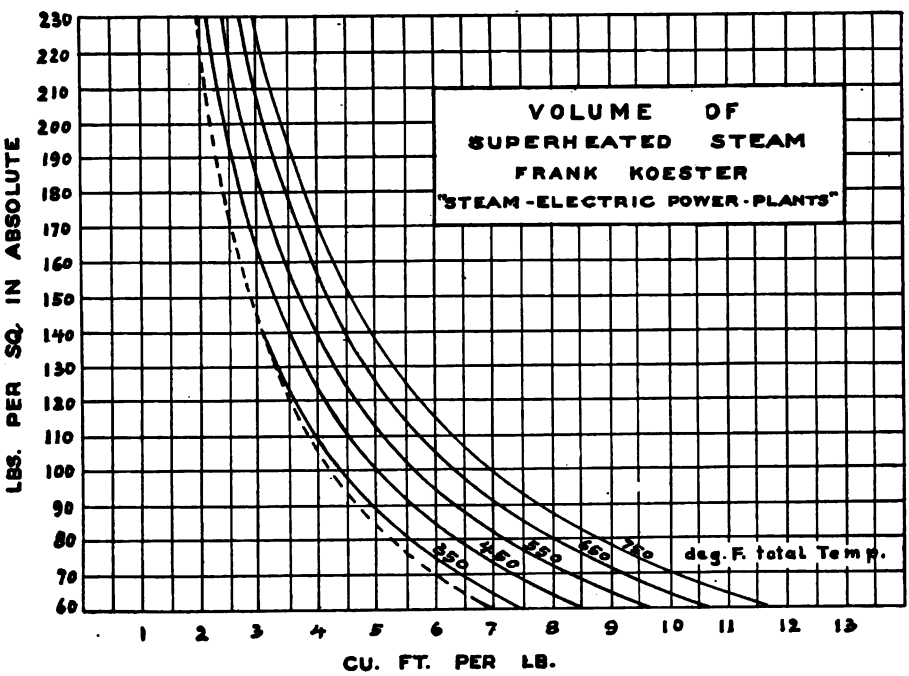


Fig. 1.

of a pipe required to transmit a certain volume of steam. For instance, assume an absolute steam pressure of 185 pounds and a total temperature of 550° Fahr. (175° Fahr. superheat) the volume will be 3 cubic feet per pound (saturated steam being 2.45 cubic feet per pound). In order to transmit 1,000 pounds of steam per minute at a

velocity of, say, 6,000 feet per minute, a pipe area of 77 square inches (10 inches diameter) will be required.

A still more convenient and fairly accurate table was presented by Mr. Foster before the American Society of Mechanical Engineers, May, 1907. By the courtesy

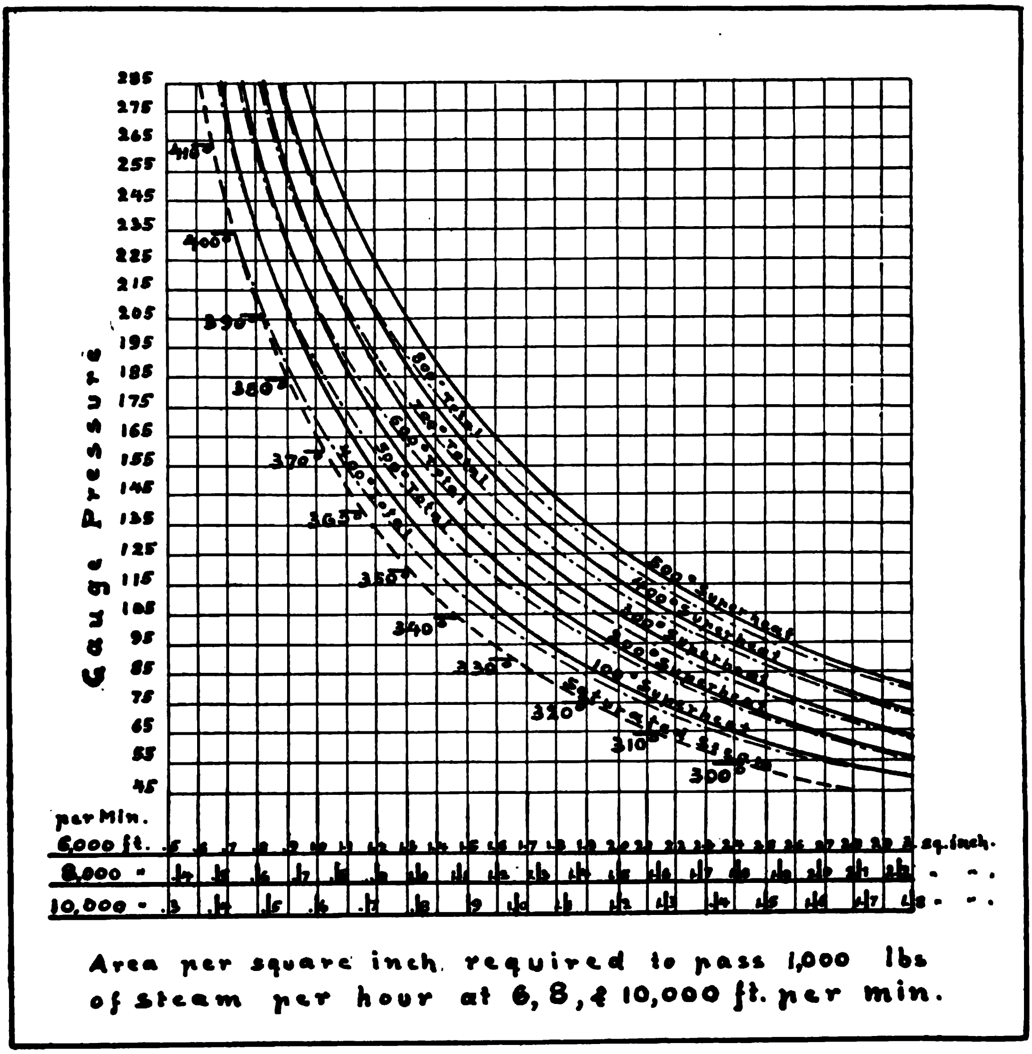


FIG. 2.

of Mr. Foster, this chart has been used in Fig. 2. The chart gives the area required in square inches to pass 1,000 pounds of steam per hour at a velocity of 6,000, 8,000 and 10,000 feet per minute.

Much has been written during the past few years regarding the great advantage in the use of a high degree of superheated steam, especially has this been done by

continental writers. This may be justified, for continental engineers have a broader experience on this subject. They point out the remarkable results obtained by the use of steam superheated to 550° or 650° Fahr. and even as high as 700° to 750° Fahr. (400° C.), the latter, however, not being everyday practice. They are right from their point of view, for manufacturers on the Continent guarantee results to this effect, their prime movers being designed to operate satisfactorily with this degree of superheat. The trouble still existing in America with certain prime movers, when supplied with steam of a total temperature of 500° to 480°, and even lower, is that the prime movers fail or other trouble ensues. It must, however, be admitted that owing to the superior skill of some manufacturers, such troubles are not universal.

Of course a prime mover operating under higher temperatures and, therefore, with a higher efficiency is more expensive, thus reducing the profit to the manufacturer on this class of apparatus, for he is obliged to sell in competition at the same price as other manufacturers. However, the ulitmate result is that the manufacturer of the high-grade prime movers sells more of his manufacture, as amply proven during the last few years.

Owing to these conditions, the highest degree of superheat actually adopted for American and English power plant practice is 150° to 170° Fahr. or a total temperature of 530° to 550°. With the above prime movers in use, it is best to supply a lower degree of temperature in order to avoid trouble in the operation of the plant, since it must be borne in mind that the higher the temperature the greater the liability to leakage, break-down, etc., which is especially true with prime movers not especially designed for a high degree of superheat.

The tendency during the past two years, probably after some manufacturers had discovered the injurious effect of the high degree of superheat on their engines, is to advocate the use of still lower degrees of temperatures than those which would be most efficient, claiming that equally good results can be obtained by 100° of superheat as by 200°.

Eminent French and German engineers, specialists and authorities on the subject state differently, although some still maintained ten years ago that there is no possible increase in the use of temperatures above 550° Fahr. But since that time prime movers have been built to stand a higher degree of temperature, so that engines and turbines are sold to-day on the Continent to work at 10 and 9 pounds per I.H.P. hour and even less. The governing conditions, however, in this country are somewhat different from abroad, owing to the difference in cost of fuel, which in Europe is practically double, and for which reason the American manufacturer may seem justified in producing only such prime movers as will operate under moderate temperatures of superheat. It must, however, be borne in mind that the ultimate aim in the design of power plants ought to be the reduction to a minimum of cost of production of a K.W., and in order to do so a high degree of superheat is essential.

CHAPTER V.

PIPING.

Introductory.—This subject is the most important part of the design of the power plant, after the general arrangement of the machinery has been laid out. The successful, economical and convenient operation of the plant depends largely on the system

1	.79	**16**	201.06	**31**	754.76	**46**	1661.91	**61**	2922.47	**76**	4536.47	**91**	6503.90
½	1.77	½	213.83	½	779.31	½	1698.23	½	2970.58	½	4596.36	½	6575.56
2	3.14	**17**	226.98	**32**	804.25	**47**	1734.95	**62**	3019.08	**77**	4656.64	**92**	6647.65
½	4.90	½	240.53	½	829.57	½	1772.06	½	3067.97	½	4117.31	½	6720.08
3	7.06	**18**	254.47	**33**	855.30	**48**	1809.56	**63**	3117.25	**78**	4778.37	**93**	6792.92
½	9.62	½	268.80	½	881.41	½	1847.46	½	3166.93	½	4839.83	½	6866.16
4	12.56	**19**	283.53	**34**	907.92	**49**	1885.75	**64**	3217.00	**79**	4901.68	**94**	6939.79
½	15.90	½	298.65	½	934.82	½	1924.43	½	3267.46	½	4963.92	½	7013.82
5	19.63	**20**	314.16	**35**	962.11	**50**	1963.50	**65**	3318.31	**80**	5026.56	**95**	7088.23
½	23.75	½	330.06	½	989.80	½	2002.97	½	3369.56	½	5089.59	½	7163.04
6	28.27	**21**	346.36	**36**	1017.87	**51**	2042.83	**66**	3421.20	**81**	5153.01	**96**	7238.25
½	33.18	½	363.05	½	1046.34	½	2083.08	½	3473.24	½	5216.82	½	7313.84
7	38.48	**22**	380.13	**37**	1175.21	**52**	2123.72	**67**	3525.66	**82**	5281.03	**97**	7389.83
½	44.17	½	397.61	½	1104.46	½	2164.76	½	3578.48	½	5345.63	½	7466.21
8	50.26	**23**	415.48	**38**	1134.11	**53**	2206.19	**68**	3631.69	**83**	5410.62	**98**	7542.98
½	56.74	½	433.74	½	1164.16	½	2248.01	½	3685.29	½	5476.01	½	7620.15
9	63.61	**24**	452.39	**39**	1194.59	**54**	2290.23	**69**	3739.29	**84**	5541.78	**99**	7697.71
½	70.88	½	471.44	½	1225.42	½	2332.83	½	3793.68	½	5607.95	½	7775.66
10	78.54	**25**	490.88	**40**	1256.64	**55**	2375.83	**70**	3848.46	**85**	5674.51	**100**	7854.00
½	86.59	½	510.71	½	1288.25	½	2419.23	½	3903.63	½	5741.47	½	7932.74
11	95.03	**26**	530.93	**41**	1320.25	**56**	2463.01	**71**	3959.20	**86**	5808.82	....	....
½	103.87	½	551.55	½	1352.65	½	2507.19	½	4015.16	½	5876.56	....	....
12	113.10	**27**	572.56	**42**	1385.45	**57**	2551.76	**72**	4071.51	**87**	5944.69	....	....
½	122.72	½	593.95	½	1418.63	½	2596.73	½	4128.26	½	6013.22	....	....
13	132.73	**28**	615.75	**43**	1452.20	**58**	2642.09	**73**	4185.40	**88**	6082.14	....	....
½	143.13	½	637.94	½	1486.17	½	2687.84	½	4242.93	½	6151.45	....	....
14	153.94	**29**	660.52	**44**	1520.53	**59**	2733.98	**74**	4300.85	**89**	6221.15	....	....
½	165.13	½	683.49	½	1555.29	½	2780.51	½	4359.17	½	6291.25	....	....
15	176.72	**30**	706.86	**45**	1590.43	**60**	2827.44	**75**	4417.87	**90**	6361.74	....	....
½	188.69	½	730.62	½	1625.97	½	2874.76	½	4476.98	½	6432.62	....	....

FIG. 1. Area of Circles.

and arrangement of pipes, and it is therefore proper that a great amount of time in designing a power plant should be spent on this subject.

The piping may be divided under two headings, high- and low-pressure. The former will consist of main and auxiliary steam piping, boiler feed, blow-off and drip systems. while the latter will consist of exhaust and exhaust drain and all piping in connection with the condenser system, as well as that of the house pumps, fire lines, boiler feed suction, etc. There are other high- and low-pressure pipings, such as oiling system which will be treated separately.

Under high-pressure we may consider pressure from 125 pounds to 250 pounds, while the low-pressure will include anything under 125 pounds.

HIGH-PRESSURE PIPING.

Size of Pipes. — The sizes of pipes depend, of course, on the character of steam to be used, for the velocity of saturated steam transmitted through a pipe is greatly reduced by friction, while superheated steam, being a rarer medium, is not so easily

Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1,292	1,767	2,488	3,014	3,786	4,904	5,927	7,321	8,535	9,717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1,096	1,328	1,668	2,161	2,615	3,226	3,761	4,282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1,070	1,263	1,576	1,837	2,092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1,116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1,707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2,435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3,335	1,281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4,393	1,688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5,642	2,168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7,087	2,723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8,657	3,326	1,146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10,600	4,070	1,403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12,824	4,927	1,698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14,978	5,758	1,984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17,537	6,738	2,322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20,327	7,810	2,691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26,676	10,249	3,532	1,102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42,624	16,376	5,644	1,761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75,453	28,990	9,990	3,117	1,378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120,100	46,143	15,902	4,961	2,193	1,172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177,724	68,282	23,531	7,341	3,245	1,734	1,044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249,351	95,818	33,020	10,301	4,554	2,434	1,465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	
Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

ACTUAL INTERNAL DIAMETERS.

FIG. 2. Equation of Pipes.

affected; the size of pipes carrying saturated steam must be larger than if superheated steam is employed.

A curve chart, showing the increase in volume of superheated steam at various pressures and different temperatures, is to be found in the chapter on superheated steam.

Common practice is to use a velocity of from 6,000 to 7,500 feet for saturated steam,

while for superheated steam 9,000 to 10,000 feet and higher may be used, this depending upon the amount of superheat.

When connecting a number of pipes to a main or larger pipe, friction should be taken into consideration; the preceding table is calculated on the rating of the actual areas of pipes and the number of pipes that can be supplied by a larger one, allowing for friction, the lower half below the diagonal blank space giving the actual areas.

In order to calculate the fall in pressure which occurs in a steam pipe, due to friction and which is increased by condensation, the following formula, given by Geipel, may be used:

$$Q = 3000\frac{\sqrt{pd^5D}}{L}$$

$$P = \frac{1}{9{,}000{,}000} \times \frac{Q^2L}{d^5D}$$

$$V = 9170\ \frac{\sqrt{pd}}{LD}$$

in which d = Diameter in inches.
L = Length in feet.
p = Loss in pressure.
D = Weight of steam in pounds per cubic foot.
Q = Pounds of steam per hour.
V = Velocity in feet per minute.

In using this formula, the number of bends and globe valves have to be taken into consideration, and allowance made for them; the following table gives the amount of this allowance for standard 90° bends:

Diameter of Pipe.	Length of Straight Pipe Allowed.
2 inches	6 feet 8 inches
3 "	10 " 0 "
4 "	13 " 4 "
5 "	16 " 8 "
6 "	20 " 0 "
7 "	23 " 4 "
8 "	26 " 8 "
10 "	33 " 4 "
12 "	40 " 0 "

General Consideration. — Among the most radical changes in power plant installation, in recent years, has been the adoption of higher pressures and higher degrees of superheat. The use of pressures ranging from 200 to 300 pounds, accompanied by temperatures of from 500° to 750° Fahr., has made necessary the design and use of heavy constructions in pipes, fittings and flanges.

In producing superheated steam it is possible to increase the steam temperature, and at the same time keep the pressure constant; the practice to-day, however, tends towards increasing the pressure also, and the time is not far distant when pressures up to 250 pounds will not be considered high. There are in operation to-day, particularly in Germany, a number of plants where pressures higher than 225 pounds are employed; one example being that of the Technische Hochschule (University) in Darmstadt, where the plant is equipped with the most modern boilers, engines and turbines, the steam being furnished at a pressure of 300 pounds and superheated to 750° Fahr. Although this plant supplies steam for various prime movers and heating purposes, the main object is more for experimental purposes in connection with the University. Another instance, as previously stated, where some 300 pounds pressure and 750° Fahr. superheated steam were used was at the St. Louis Exposition in 1904, where a Delaunay Belleville boiler furnished steam to a 6-cylinder, quadruple expansion, 1,500 horse-power engine of the same make.

The use of steam at high temperature naturally means an increase in the expansion of the pipe, and the use of high pressure demands the use of high-grade material and heavy construction. There are also other important factors which must be considered, such as the system of piping. As the steam line is in reality the main artery of the plant, it is of the utmost importance that it be so designed that an accident to a portion of it will not result in shutting down the entire plant. The liability of rupture may be minimized by selecting the highest grade of material on the market, and being sure that the system adopted for the main steam pipes is such that, in case of a failure, a particular section may be cut off, and steam thrown over to an emergency line. In doing so, of course, care must be taken to design the system as simple as possible, and so flexible as to permit of any section being cut out at a moment's notice, without shutting down the adjacent engines.

System of Piping. — There are two main types of power plants in general use. In one of these the engine and boiler rooms lie parallel to each other, and in the other the boilers are arranged at 90° to the generating room. However, there are other plants installed where the boilers are situated at the end of the generating room, and in certain instances the boilers have been located above the generating room; both layouts being chosen on account of space conditions. This same consideration also governs to a great extent the layout of the pipe system. For instance, the third mentioned arrangement of boiler and generating room usually requires an extremely long main steam pipe. Should this be one single line it will readily be seen that when a rupture of a pipe connection occurs near the generating room it will result in shutting down the entire plant. Therefore a double header or ring system may be advantageously employed. In the other mentioned arrangements the single, double header, or ring system may be used. These three pipe systems are shown in the following illustrations.

The single header system usually consists of a line run at the back, or above the boilers, to which are connected the lines from the boilers, the connections either

entering from the sides or dropping from above the main header. The arrangement of valves is such that any boiler may be easily disconnected from the header, either automatically or by hand. The steam line to the prime movers is taken from this main header, usually from the top, in order to prevent the condensation which may have accumulated in the header from entering this pipe.

The disposition of valves, both in the main line and in the branches, should be of a character to insure flexibility of operation and to enable the steam to be drawn from any or all of the boilers, as may be necessary, and so that the line of any engine may

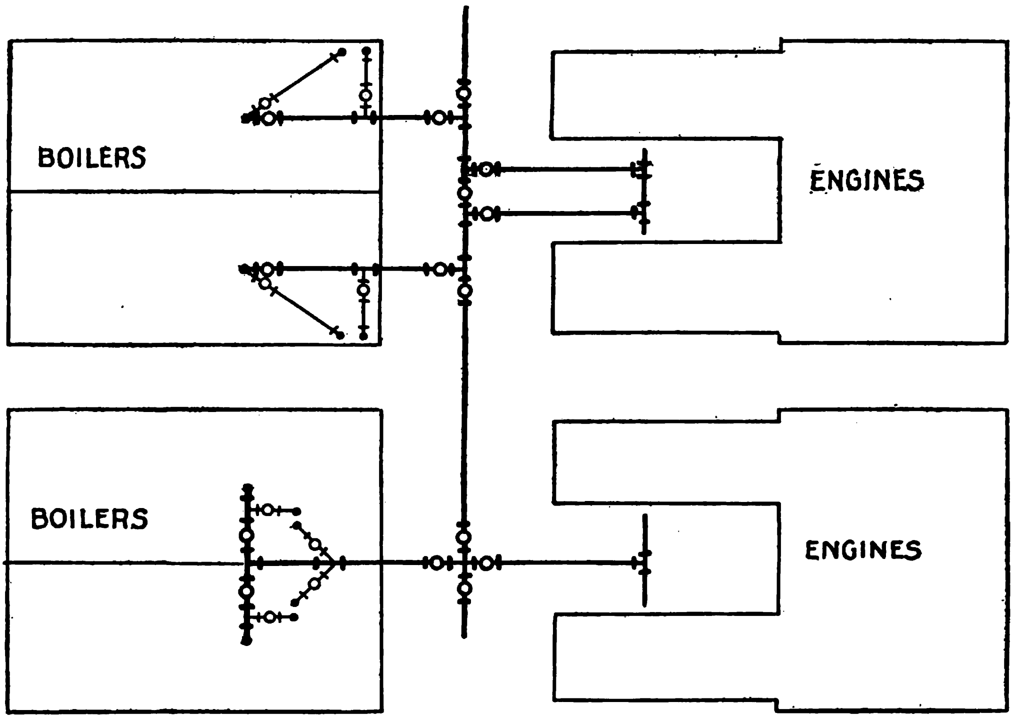


FIG. 3. Single Header System.

be disconnected. The general character of this single header system is shown in Fig. 3, and on account of the extreme simplicity of this system it is very commonly used. It will be noticed that Fig. 3 shows a single main pipe from two boilers (one battery) which have been cross-connected, leading directly to the main header from which the engine is supplied. Only a few valves have been employed, although it might be easily arranged to supply the adjacent engine from this battery, or even a single boiler. The fine drawn lines throughout the figures from 3 to 5 indicate the steam-pipe connections to and from the superheaters, which are placed directly in the boiler setting. It will also be observed that valves have been provided to cut out the superheater and use saturated steam.

The top of Fig. 3 shows the same single header system, with each boiler having a

separate line, [as these two boilers (one battery) supply steam for one engine, and as each boiler has its own supply pipe to the header], corresponding arrangement has been provided from the header to the engine, this practice, however, being rarely used.

The multiple header system consists of two or more headers to which the connecting pipe lines from the boilers are joined, and from which branches are led to the engines. The general arrangement of this system is shown in Fig. 4, and from these diagrams it will be seen that the arrangement is a very flexible one, providing as far as possible against interruption of the service. Two possible methods of cross-connec-

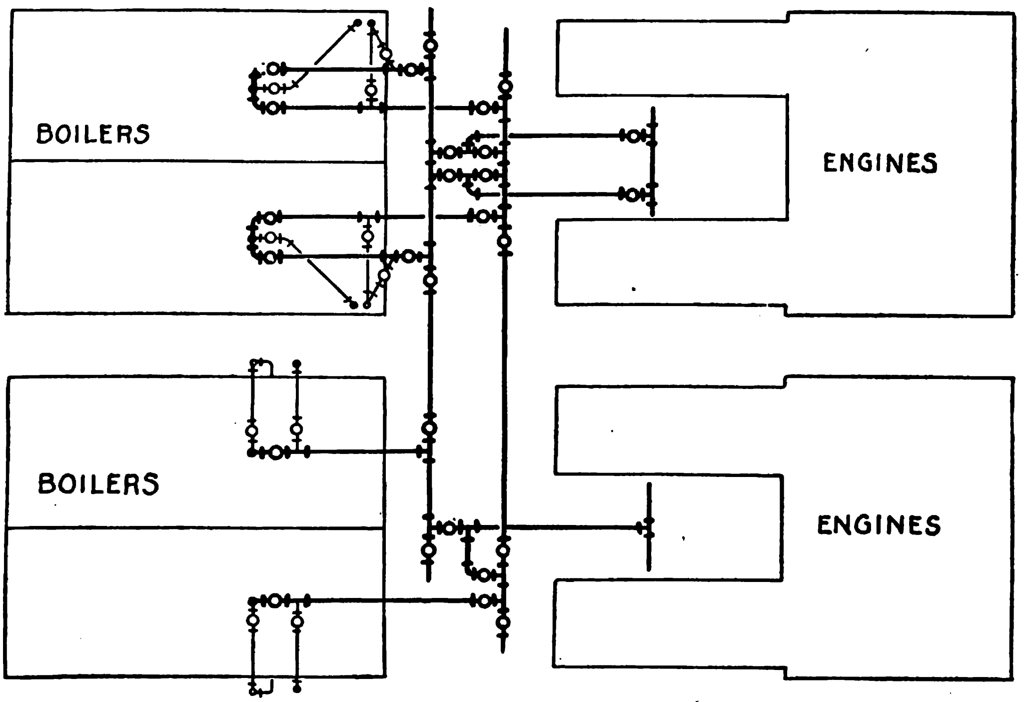


FIG. 4. Double Header System.

tion are shown in this illustration, and it will be observed in the upper end method that flexibility is obtained at the cost of numerous valves and fittings. It is apparent that there is an almost infinite number of ways in which multiple headers may be connected, but in any event the object of this system is to provide an extra header to carry the load in case of emergency, and the best method of cross-connecting is that which requires the minimum number of valves and fittings, and at the same time is the most flexible.

The general arrangement of the ring system is shown in Fig. 5, the main steam header being in the form of a closed ring, which may be split into sections by means of suitably placed valves. There are numerous variations possible with this arrangement; *e.g.*, where the header runs round both sides of the boiler room, the two sections

may be cross-connected at desirable points, or where the two sections of the ring are close together, on account of the expansion in short cross-connections, the rings should be closed at the ends by means of flexible bends. Double ring systems have never been employed, because the single header has been found to answer the purpose just as efficiently, and without the unnecessary complications attached to the previous mentioned system. However, a header system of more than two main lines has been installed in the 59th Street power house of the Subway system of New York City, where some 60 boilers and 9 main engines have been connected by a 3-header system.

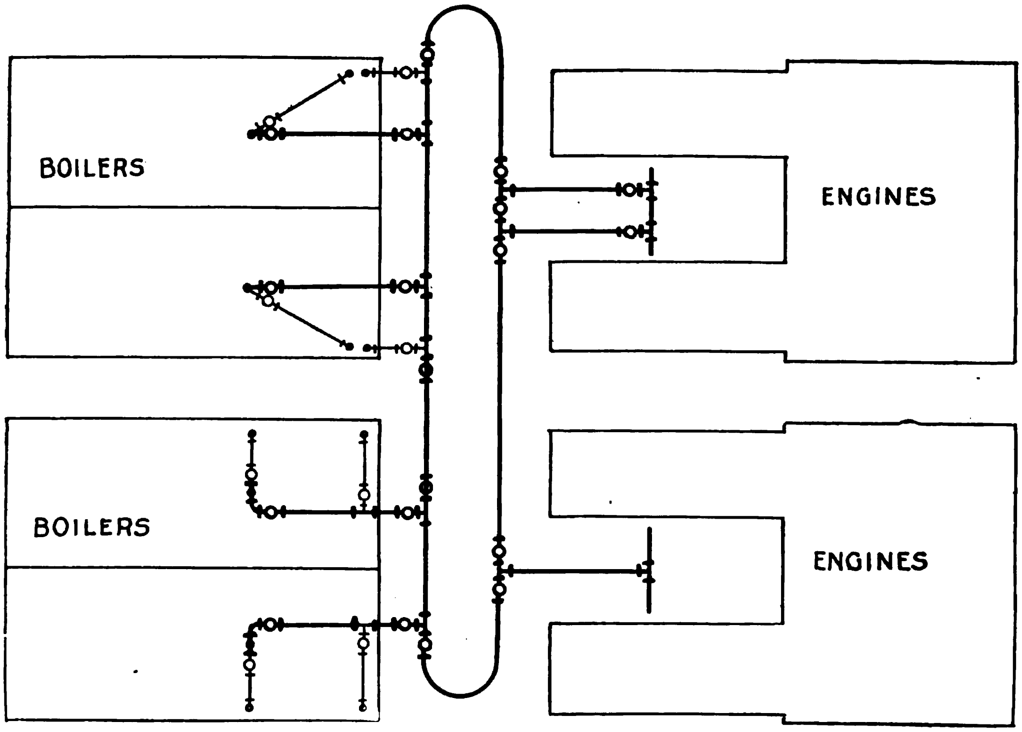


FIG. 5. Single Ring System.

This 3-header steam-pipe system was installed for the purpose of equalizing the steam pressure of the entire plant. The pipes, which are 10 inches in diameter, are arranged one above the other in a so-called separate pipe area. As this plant is 693 feet long, it will be readily seen that a large amount of expansion must be taken up in these lines, and for this purpose the pipes are arranged in snake lines. At the junction of an 18-inch main cross steam pipe leading from a group of six 600-horse-power boilers is placed a manifold. At the junction of this pipe and that of the three equalizing pipes are placed valves, to cut off either the supply pipe from the boilers or either one of the equalizing pipes. The accompanying illustration, Fig. 6, shows this. As these pipes are some 20 feet above the engine-room floor level, and as the pipe con-

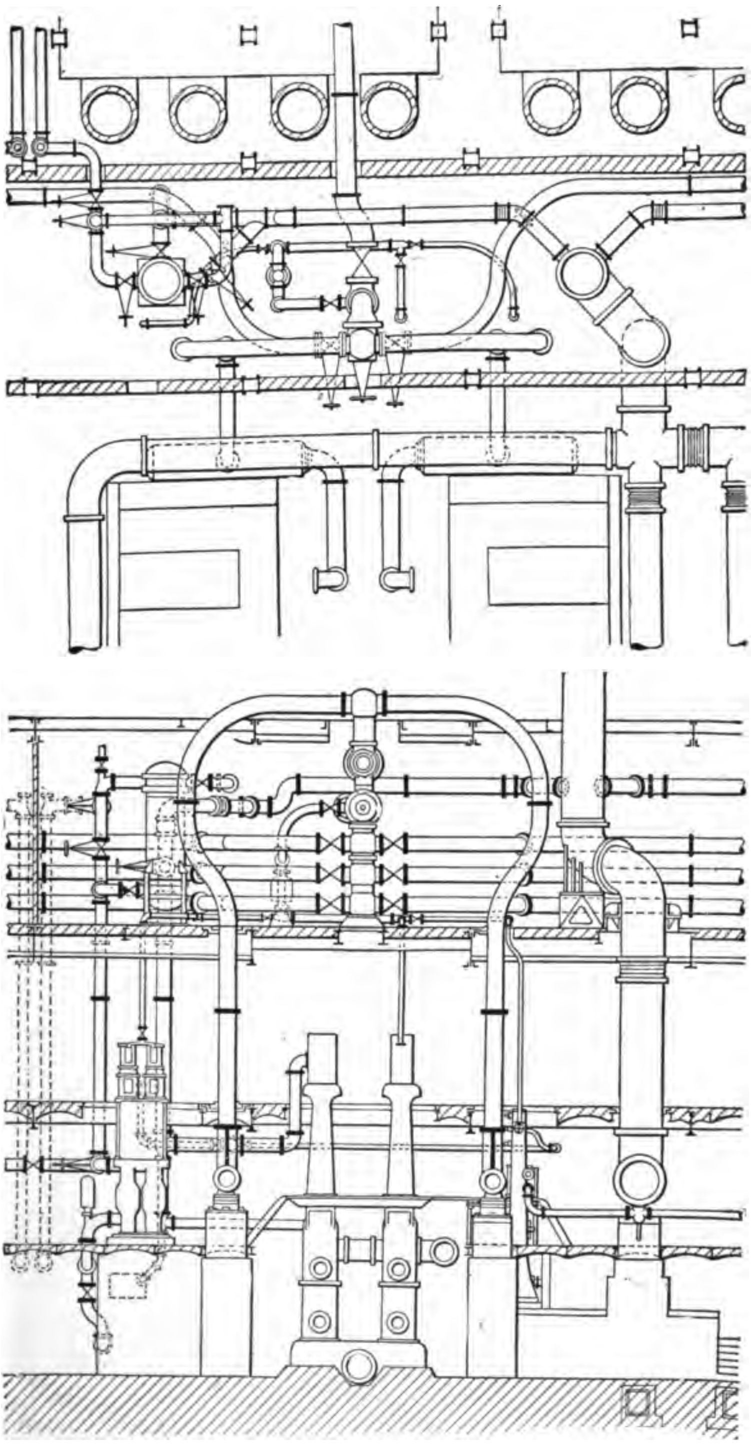


Fig. 6. Three-Header Piping System (59th St. Plant, New York).

nections to the engines are made in the basement, it was found necessary to install long vertical risers or so-called "steam down-takes." These steam down-takes, it will be observed in the illustration, appear in goose-neck form in order to take up the expansion and contraction of the pipes. A quick closing valve has been placed above the before-mentioned manifold, and may be operated from a distance in case of emergency, thus shutting off the two main down-takes connecting to one engine. These illustrations are taken from an article by the author which appeared in *The Engineer* of December, 1904.

Expansion.—As already pointed out, proper means must be provided for taking up expansion and contraction of all pipe lines, without any excessive strain on the fittings. In modern practice the expansion is of great importance, on account of the use of high degrees of superheat. Take, for example, a line carrying dry saturated

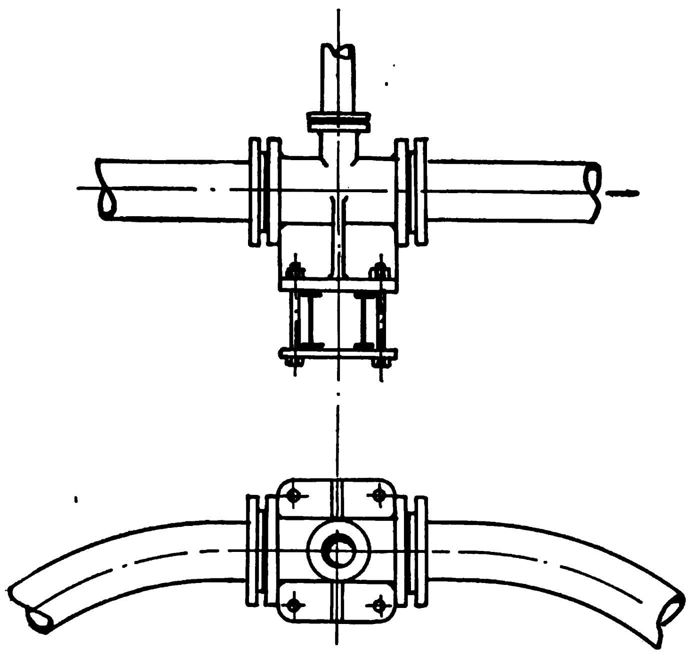


FIG. 7. Cast-Iron or Semi-Steel Anchor.

steam of 175 pounds gauge pressure (377° Fahr.), the same steam superheated 150° Fahr., as is commonly employed in America and Great Britain, would have a total temperature of 527° Fahr., and assuming a temperature of some 90° or 100° either above the boiler or in the pipe trenches, wherever the pipes may be placed it would give a difference in temperature of 430° Fahr. The expansion due to this 430° Fahr. has to be taken up in the expansion allowance of the pipe system. The calculation of the expansion of, say, one hundred feet of pipe may be easily accomplished by the following data: for each 1° Fahr. in difference, the expansion will be .0000067 of an inch

per inch, or approximately .00008 of an inch per foot. A more convenient form of this data for one working with a number of pipe lines at a given temperature is to reduce the coefficient so as to apply to ten-foot pipe lengths, which for the above

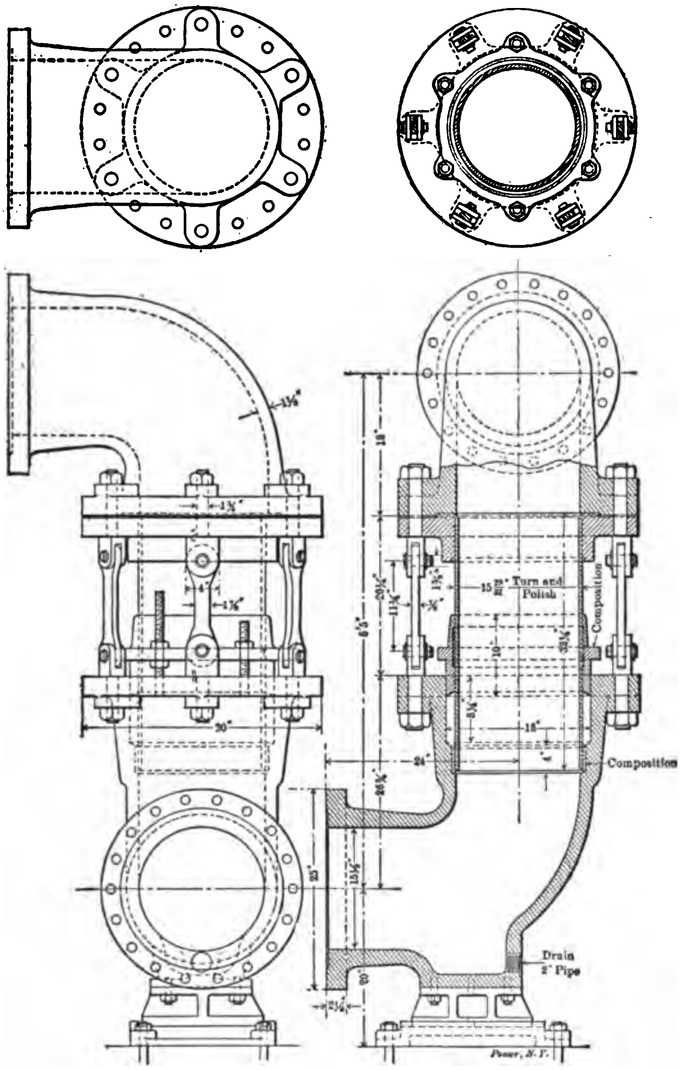


FIG. 7a. Swivelling Joint for High-Pressure Steam.

temperature (430° Fahr.) is .34 inch. This constant applies to wrought iron or steel, while the coefficient of cast iron is .0000059 per degree Fahrenheit per unit of length. As the difference is so small, the coefficient for wrought iron is usually employed.

Anchors. — In order to have the expansion equally distributed over the piping, it is of importance properly to locate the anchors; these anchors are not only installed

on account of expansion, but to minimize the vibration of the piping and, therefore, they should be placed where the vibration is the greatest. Anchors are designed usually to suit a particular condition, and are either bolted direct to the structural steel or tied by rods and turn-buckles. The accompanying illustrations show some

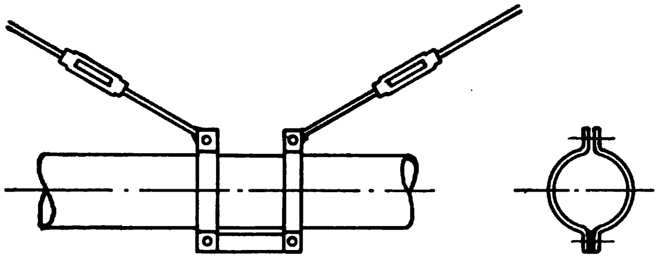


FIG. 8. Pipe Anchor.

types of anchors; Fig. 7, representing an anchor consisting of a tee, with a foot cast on, so that it can be bolted direct to the steel work, or to the wall to suit the conditions, while Fig. 8 shows one made entirely of wrought iron, and composed of two bands of flat iron tied together on the back with a distance piece. Two tie-rods are employed to pull apart these bands and, the more they are pulled apart, the tighter the clamp

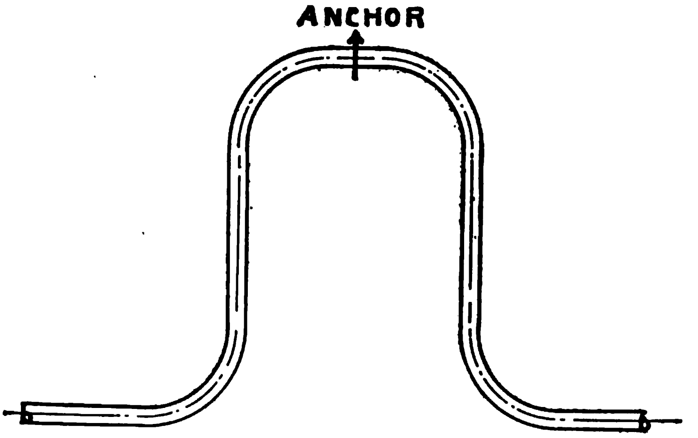


FIG. 9. Location of Anchor.

will hold. This anchor is cheap and simple, yet efficient, and will serve practically for any anchorage.

Where long "U" bends are installed to take up the expansion, the author would suggest to locate the anchor in the middle of the bend, as shown in Fig. 9, in which case either of the above anchors may be employed.

Supports and Hangers.—As there are only a few anchors, the remainder of the piping must be supported either by means of brackets or hangers. It is impossible

here to state how far apart these hangers or supports are to be placed, but they should be in sufficient number to take any strain off the flanges of the piping. Where fittings, valves, etc., increase the weight of the pipe line, hangers or supports should be placed, not only on account of the increased weight, but also of the increased vibration at these points.

Hangers are usually made of a wrought-iron band, in halves, clamped around the pipe and suspended by a rod and turn-buckle from any convenient point. In case the pipe has to be supported from below, cast-iron or structural steel brackets may be employed. These brackets are frequently provided with roller bearings, as seen in

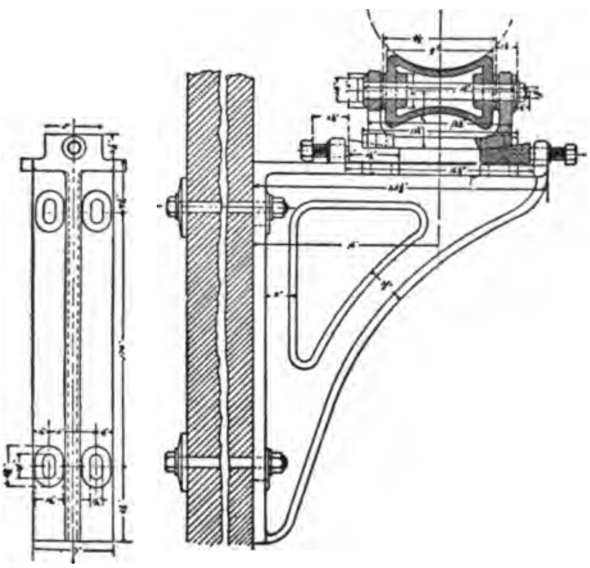


FIG. 10. Bracket with Adjustable Roller Bearing.

some of the accompanying illustrations. Fig. 10 shows a bracket with adjustable roller bearing as manufactured by the Walworth Manufacturing Company, while the two upper brackets, shown in Fig. 11, as manufactured by the Crane Company, have brackets with a roller attached and one with the pipe strapped down to the bracket; the latter illustration, Fig. 11, shows a number of features applicable to various arrangements. Frequently supports are required for vertical risers; an example of such is shown in Fig. 12, a number of which were installed in the 59th Street power house of New York. Where expansion or contraction has to be taken care of in a riser, proper means must be provided, either by a spring system or a counterbalanced system to allow for same. A type of the latter is shown in Fig. 13, which has been installed in the University plant at Darmstadt, Germany. It will be seen that the pipe may move in a horizontal or vertical direction, the horizontal movement being taken care of by the knife-edges, which rest on roller bearings, while the vertical movement is taken care of by two counterweights; for ordinary power plant work this system may be easily simplified.

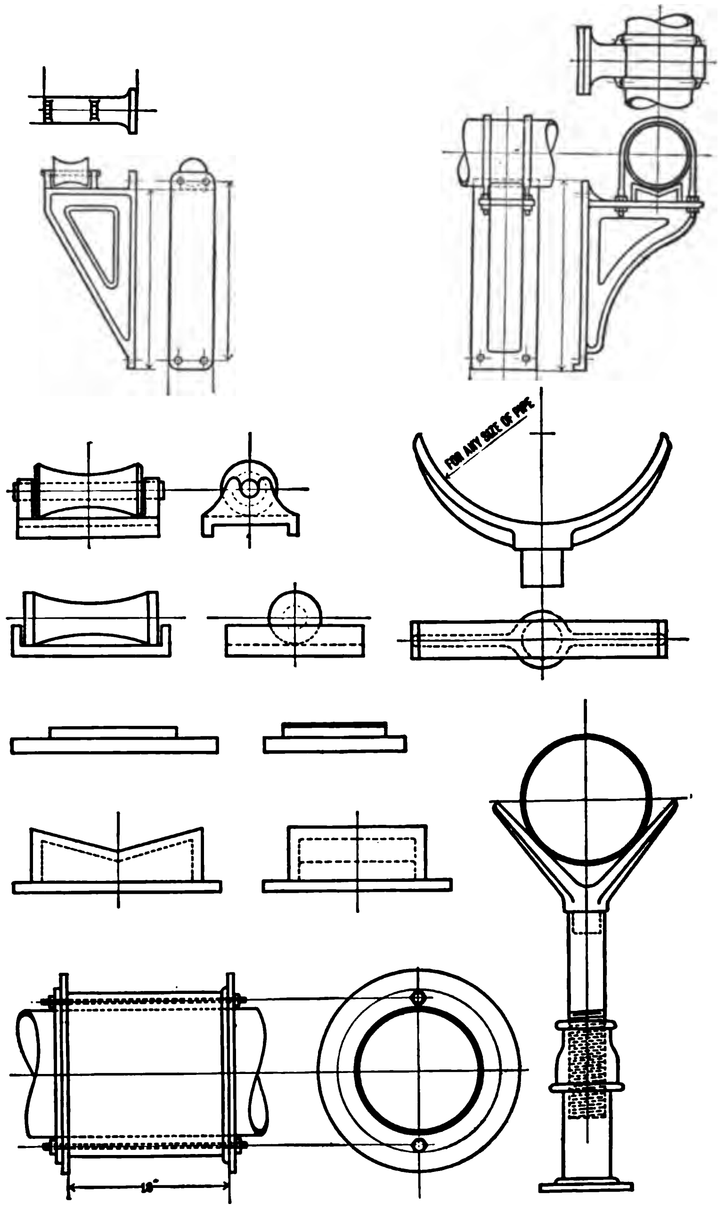


FIG. 11. Pipe Supports, Anchor and Wall Sleeve.

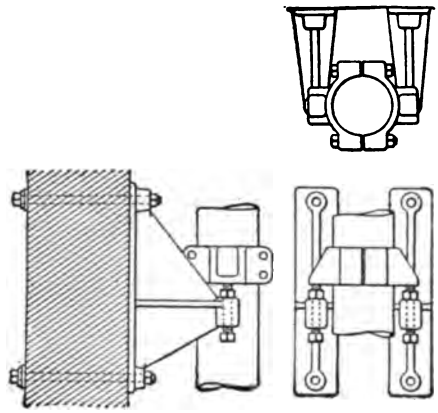


FIG. 12. Bracket for Pipe Riser.

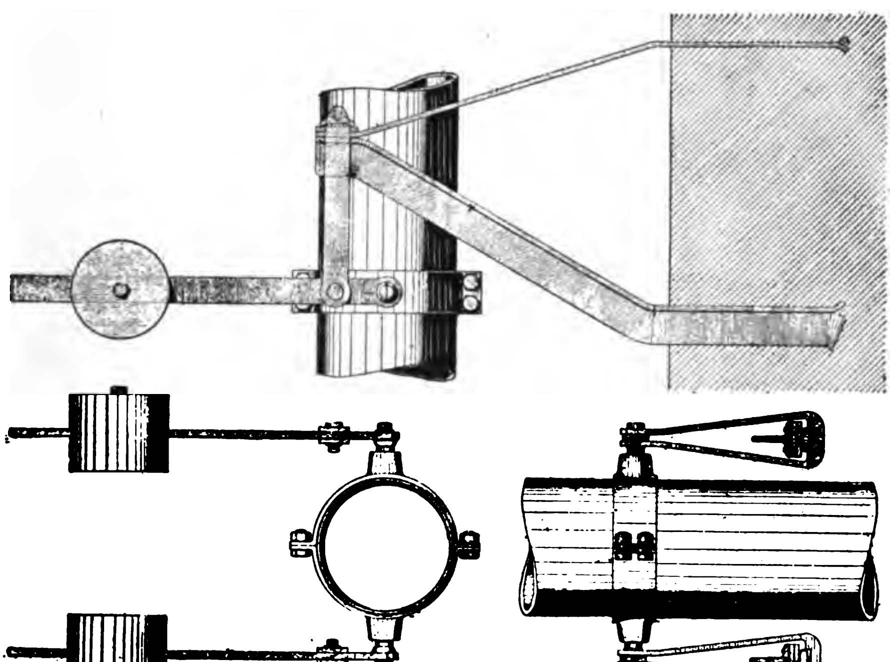
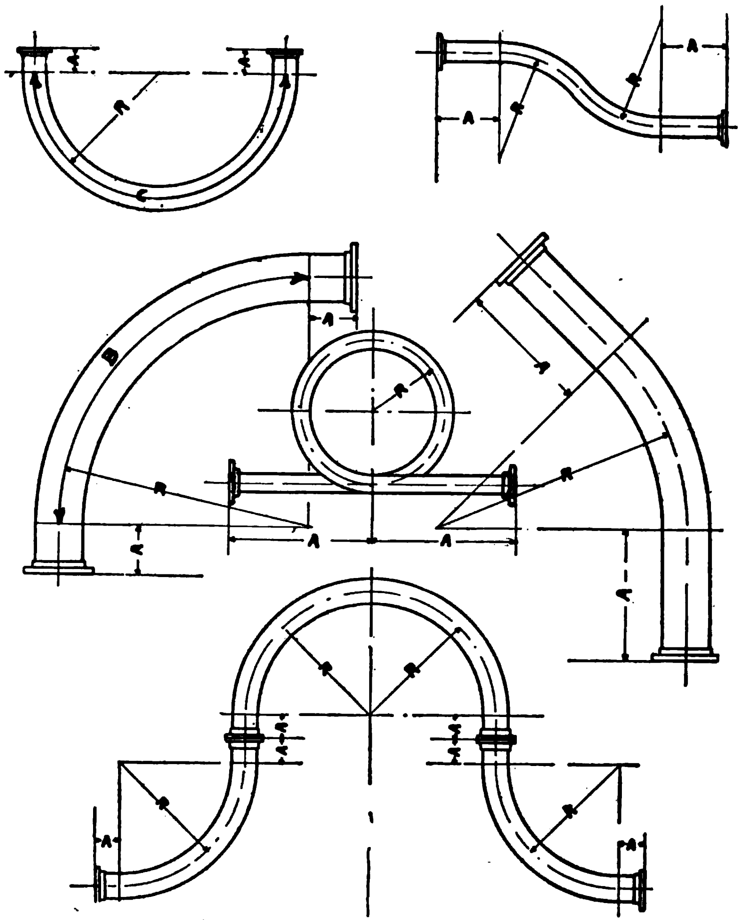


FIG. 13. Balanced Support for Pipe Riser, allowing movement in vertical and horizontal direction.



SIZE	A Ft.	A In.	B Ft.	B In.	C Ft.	C In.	R Ft.	R In.	Total Pipe Required 90° Bend Ft.	Total Pipe Required 90° Bend In.	Total Pipe Required 180° Bend Ft.	Total Pipe Required 180° Bend In.
1		2		6¼		12½		4		10¼		16½
1¼		2		9⅝		18¾		6		13⅝		22¾
1½		2½		9⅝		18¾		6		14⅝		23¾
2		3		14⅛	2	4¼		9		20⅛	2	10¼
2½		3½		18⅛	3	0¼		12		23⅛	3	7¼
3		4		23⅛	3	11		15	2	7½	4	7
3½		4½	2	4⅛	4	8½		18	3	1¼	5	5½
4		5	2	7⅝	5	2¾		20	3	5⅝	6	0¾
4½		5½	2	10½	5	9		22	3	9½	6	8
5		6	3	1¾	6	3½		24	4	1¾	7	3½
6		6	3	11⅛	7	10¼	2	6	4	11⅛	8	10¼
7		6	4	8½	9	5	3	0	5	8½	10	5
8		6	5	6	11	0	3	6	6	6	12	0
9		6	6	3⅜	12	6¾	4	0	7	3⅜	13	6¾
10		6	7	0⅞	14	1¾	4	6	8	0⅞	15	1¾
12		6	8	3	16	6	5	3	9	3	17	6
14		20	9	5⅛	See Note "1"		6	0	12	9⅛	See Note "1"	
15		20	10	2½	"	"	6	6	13	6½	"	"
16		20	11	0	"	"	7	0	14	4	"	"
18		24	12	6¾	"	"	8	0	16	6¾	"	"
20		24	14	1⅝	"	"	9	0	18	1⅝	"	"
22		24	14	11⅛	"	"	9	6	18	11⅛	"	"
24		24	16	5⅞	"	"	10	6	20	5⅞	"	"
26	2	6	See Note "2"		"	"	12	0	See Note "2"		"	"
28	2	6	"	"	"	"	16	0	"	"	"	"
30	2	6	"	"	"	"	18	0	"	"	"	"

1. Special designs submitted for expansion bends of 14" and larger.
2. Special designs submitted for 90° bends of 26" and larger.
3. If plain ends are required on bends 12" and smaller add 12" to total length.

FIG. 14. Various Shapes of Bends with Table of Dimensions.

Fittings.—In order to decrease the cost of piping as well as to minimize the liability of leakage, the number of fittings should be reduced as much as possible. Modern

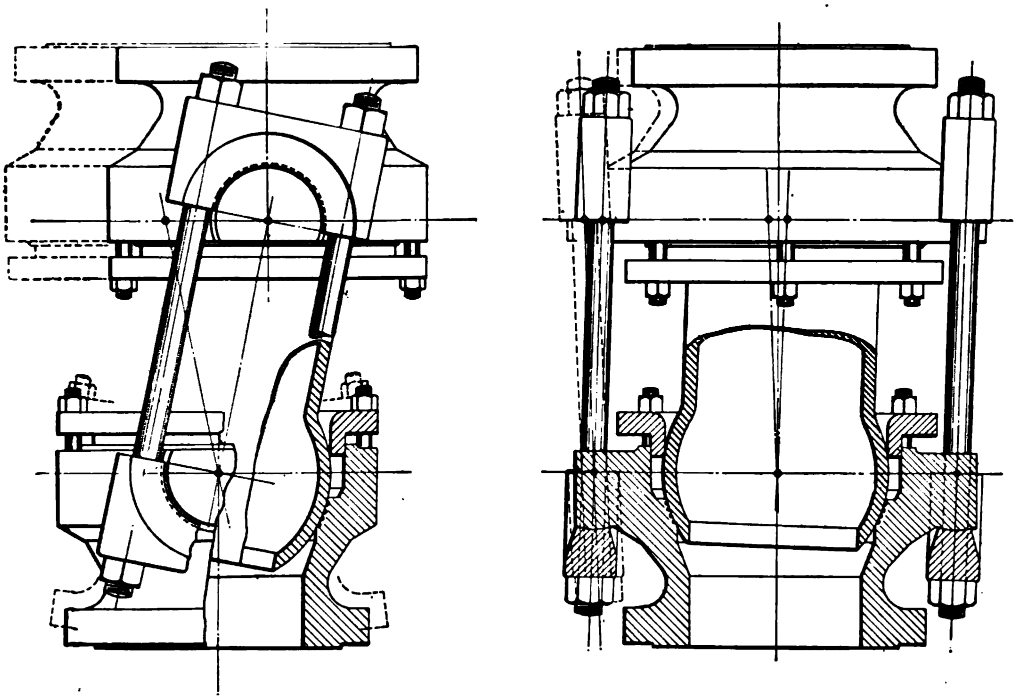


FIG. 14a. Harters Expansion Joint.

practice is to use welded or seamless drawn steel pipe. These pipes are usually obtained in America in lengths up to 20 to 21 feet, while in Europe, and especially on

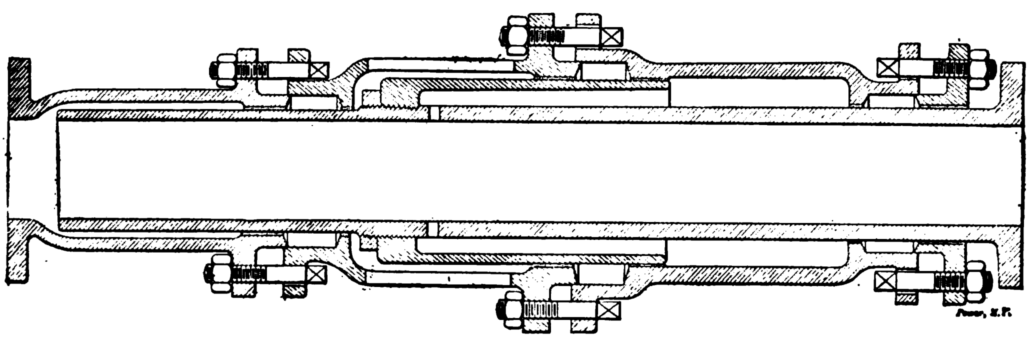


FIG. 14b. Slip Joint.

the Continent, pipes in lengths up to 50 feet are easily obtainable. The benefit of using long lengths consists in the reduced cost of piping due to the fewer joints, which at the same time reduce the liability of leakage.

Wherever possible cast elbows should be avoided and pipe bends similar to those illustrated in Fig. 14 employed. The radius of these bends must be at least five to six times the diameter of the pipe, while in exceptional cases four times the diameter may be taken. This latter, however, is not favored, owing to the difficulty in manufacturing same. A straight length of pipe should be left on the end of the bend, as indicated by "A" in Fig. 14, which varies in different size pipe and different manufactures. For instance, a 14-inch pipe may need 20 inches of straight length, while a 6-inch pipe needs 6 inches straight length, according to attached table, which is from the Pittsburg Valve, Foundry and Construction Company.

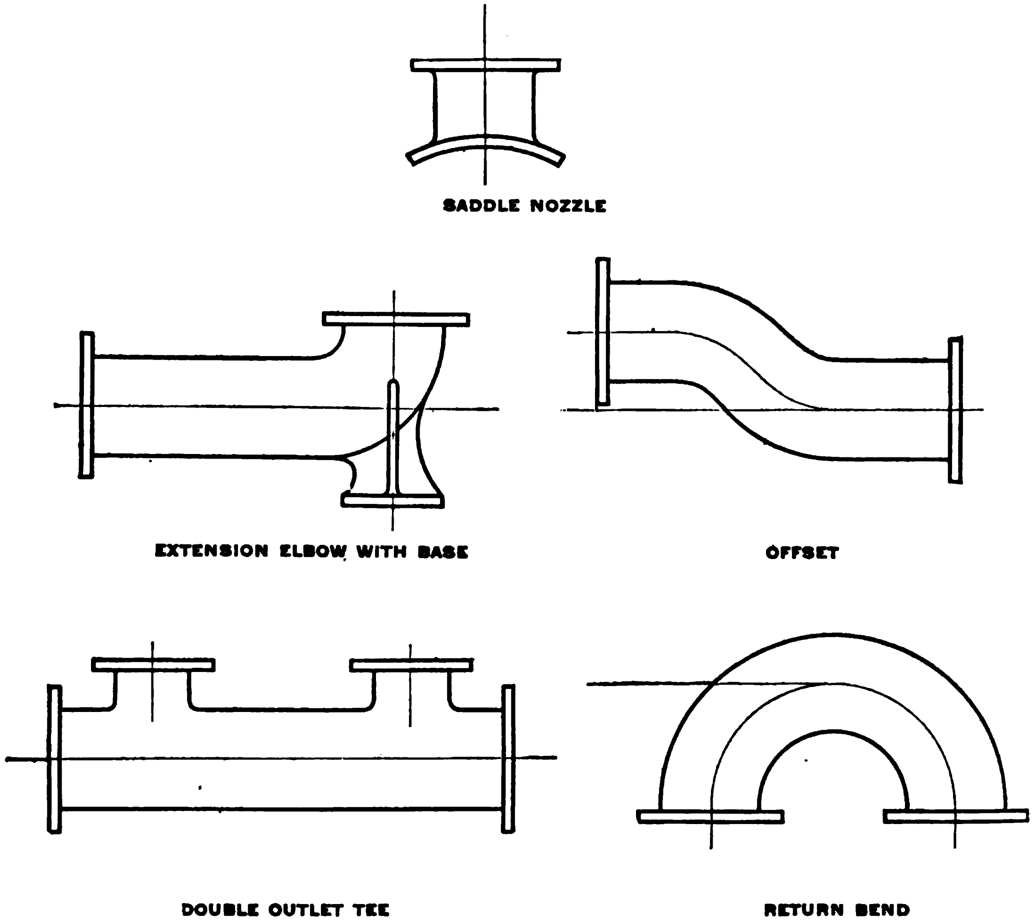
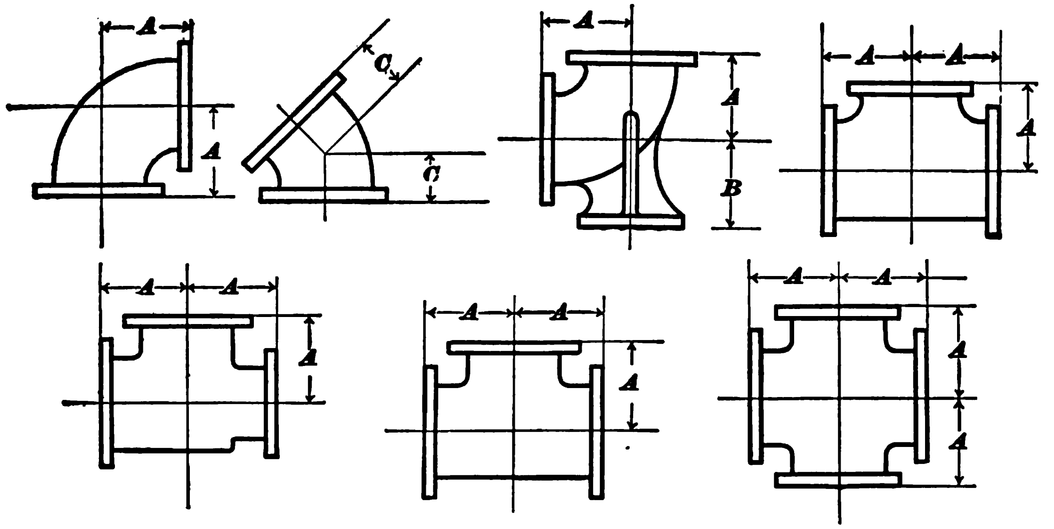


FIG. 15. Cast Fittings.

Where space and conditions do not allow of using long radius bends, cast fittings must be employed. These should be made of first-class cast-iron, steel or semi-steel; such fittings are illustrated in Figs. 15 and 16; the latter is accompanied by a table, giving the main dimensions for fittings suitable for 250 pounds working pressure and are of the Crane Company's make. These dimensions vary slightly, according to



Size of Run.......	Inches.	2	2½	3	3½	4	4½	5	6	7	8	9
Outlets..........		ALL REDUCING FITTINGS 2" TO 9" INCLUSIVE ARE THE SAME DIMENSIONS AS STRAIGHT FITTINGS CENTER TO FACE.										
Face to face......	A A	10	11	12	13	14	15	16	17	18	20	21
Cent. to face......	A	5	5½	6	6½	7	7½	8	8½	9	10	10½
Cent. to Face of 45° Ells...	C	3	3½	3½	4	4½	4½	5	5½	6	6	6½
Cent. to base of base Ells. .	B	5½	6	6¼	6¾	7	7¼	7½	8	8¾	9¼	10
Diameter of Flanges.....	Inches.	6½	7½	8¼	9	10	10½	11	12½	14	15	16
Thickness of Flanges.....	Inches.	⅞	1	1⅛	1 3/16	1¼	1 5/16	1⅜	1 7/16	1½	1⅝	1¾

Size of Run.......	Inches.	10	12	14	15	16	18	20	22	24		
Outlets..........		7 and Larger	9 and Larger	10 and Larger	10 and Larger	12 and Larger	14 and Larger	16 and Larger	16 and Larger	16 and Larger		
Face to face......	A A	23	26	29	30	32	34	37	40	44		
Cent. to face......	A	11½	13	14½	15	16	17	18½	20	22		
Cent. to face of 45° Ells...	C	7	8	8	8½	9	9½	10	10½	11½		
Cent. to base of base Ells..	B	10½	11	14	14½	15¼	15½	16¾	17¾	18¾		
Diameter of Flanges.....	Inches.	17½	20	22½	23½	25	27	29½	31½	34		
Thickness of Flanges.....	Inches.	1⅞	2	2⅛	2 3/16	2¼	2⅜	2½	2⅝	2¾		

TEES INCREASING ON THE OUTLET

Tees having outlet larger than the run will be the same length center to face of all openings as a Tee with all openings of the size of the outlet.

EXAMPLE

A 12" x 12" x 18" Tee will be governed by the dimensions of the 18-inch Tee, namely, 17 inches center to face of all openings, and 34 inches face to face. The face to face dimensions of Flanged Fittings are not changed by a reduction on the run.

FIG. 16. Fittings Suitable for 250 lbs. Working Pressure (Crane Co).

different manufacturers. Some engineers condemn cast iron altogether for any part of a modern pipe line.

For a number of years cast fittings have been done away with in Europe to a great extent and have been replaced by welded fittings; a good example of this practice is the piping system of the new Summer Lane plant, Birmingham, England.

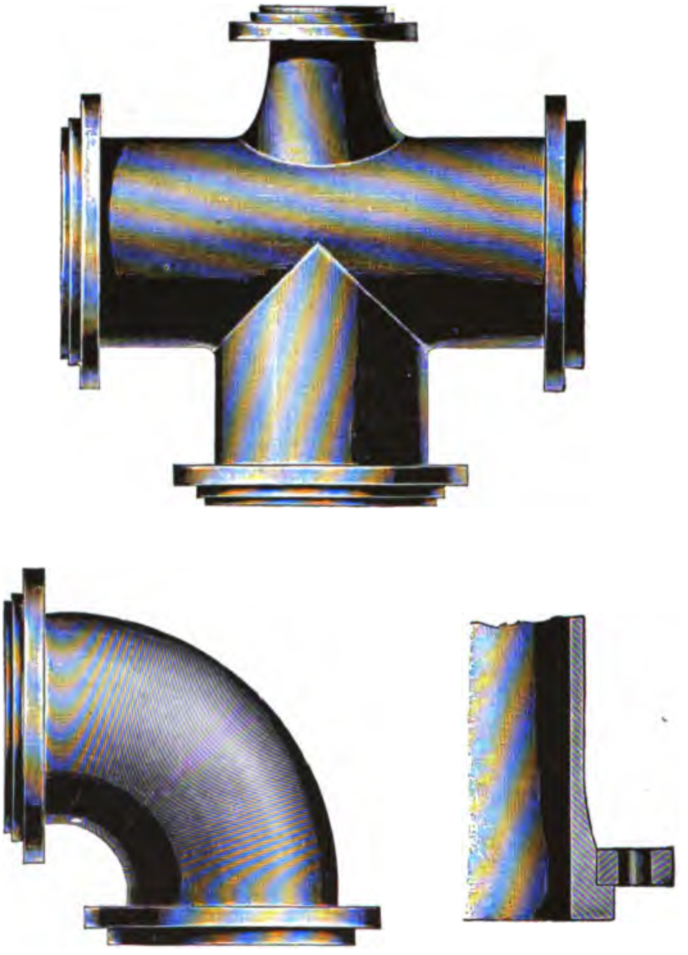


FIG. 17. Welded Steel Fittings with loose flanges.

Fig. 17 represents such fittings made up entirely of wrought iron or steel; as will be noticed in the illustration, these fittings are provided with loose movable flanges. Practically any desired form or size may be obtained, an example of which is given in Fig. 18, which represents a manifold. These fittings are, of course, more expensive than common cast-iron ones; the process of making them is not a secret, and a number of manufacturers, especially abroad, turn them out under various processes. The

author is of the opinion that within some years these fittings will be generally found in power-house practice, as their many advantages are obvious.

FIG. 18. Welded Manifold with Loose Flanges.

In calculating the thickness of the walls of pipes or fittings, a factor of safety of from five to eight should be allowed.

The tensile strength of good pipe material averages as follows:

MATERIAL.	TENSILE STRENGTH IN POUNDS PER SQUARE INCH.
Cast Iron	15,000
Copper	30,000
Wrought Iron	50,000
Mild Steel	60,000

A formula for calculating thickness of pipe shell is as follows:

$$t = \frac{pds}{T}$$

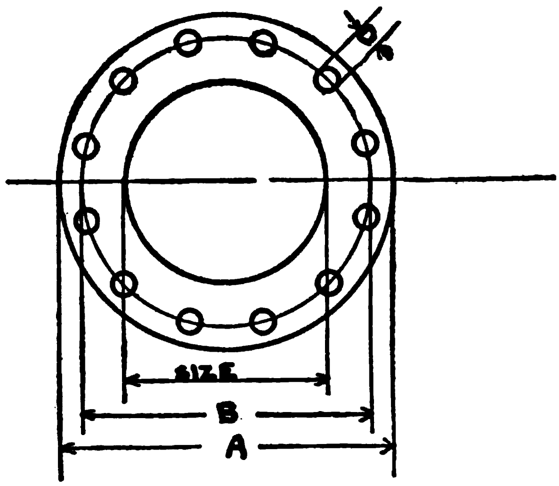
in which

t = Thickness of pipe shell in inches.
p = Pressure in pounds per square inch.
d = Internal diameter in inches.
T = Tensile strength.
S = Factor of safety.

Where globe valves are employed, twice the above lengths should be added for each valve. Where other fittings, such as long sweep ells, manifolds, etc. are used, the designer must use his own judgment.

Flanges.—The most important part of a fitting is the flange, as it is upon this that the principal cost of maintenance depends. Although each manufacturer may have a specially designed flange, there is in America a standard flange, which was agreed upon by the leading manufacturers at a meeting held June 28, 1901; this is known as the Manufacturers' Standard (see Fig. 19). Many power plant designers, however, have their own flange, one of which is given in Fig. 20, and was originally designed for the

59th Street station in New York, and has since been used in several other plants. It will be noticed that these fittings are of unusual strength; the left-hand illustration

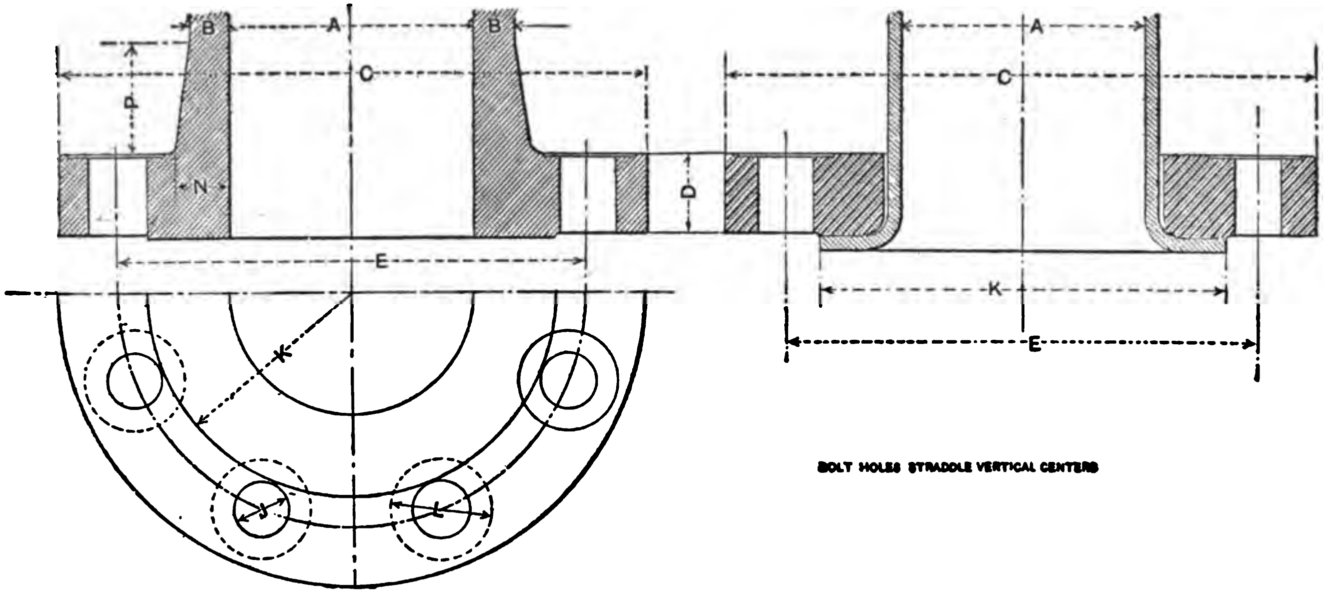


SIZE	A	B	No. Holes	D	Size Bolt	Length of Bolt
1	4½	3⅛	4	⅝	½	2
1¼	5	3¾	4	⅝	½	2¼
1½	6	4½	4	11/16	½	2½
2	6½	5	4	11/16	⅝	2½
2½	7½	5⅞	4	¾	⅝	2¾
3	8¼	6⅝	8	¾	⅝	2¾
3½	9	7¼	8	13/16	⅝	2¾
4	10	7⅞	8	13/16	⅝	3
4½	10½	8½	8	⅞	¾	3¼
5	11	9¼	8	⅞	¾	3¼
6	12½	10⅝	12	⅞	¾	3½
7	14	11⅞	12	1	¾	3¾
8	15	13	12	1	⅞	3¾
9	16	14	12	1	⅞	4
10	17½	15¼	16	1	⅞	4
12	20	17¾	16	1	⅞	4¼
14	22½	20	20	1	⅞	4½
15	23½	21	20	1⅛	1	4¾
16	25	22½	20	1⅛	1	5
18	27	24½	24	1⅛	1	5¼
20	29½	26¾	24	1¼	1⅛	5½
22	31½	28¾	28	1¼	1⅛	5¾
24	34	31¼	28	1¼	1⅛	6
26	36¼	33½	32	1¼	1⅛	6¼
28	38½	35¾	32	1¼	1⅛	6½

NOTE.—Flanges, Flanged Fittings, Valves, etc., are drilled in multiples of four, so that fittings may be made to face in any quarter and holes straddle center-line.

FIG. 19. Standard Flange Drilling for 175 lbs. Working Pressure, adopted by the leading manufacturers of America, June 28, 1901.

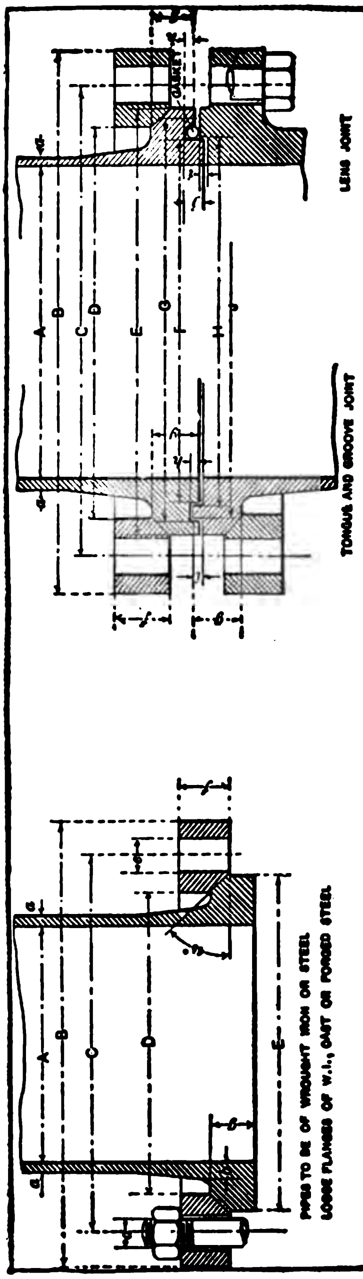
in Fig. 20 represents a cast-iron or semi-steel flange, while the right-hand is of the loose flange type. This flange is usually, but erroneously, called in America the Van Stone



Diameter of pipe (inside)	A	1½	2	2½	3	4	5	6	7	8	9	10	12	14	16	17
Thickness of shell	B	7/16	½	9/16	⅝	¾	13/16	15/16	1	1 1/16	1⅛	1 3/16	1¼	1⅜	1½	1⅝
Diameter or flange	C	6	6½	8	9	10¾	12	13¾	14¾	16¾	17½	19¼	21½	23¾	26	27½
Thickness of flange	D	¾	1	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2 1/16	2⅛	2¼	2⅜	2½	2⅝
Diameter of bolt circle	E	4½	5	6¼	6⅞	8½	9⅝	11	12¼	13½	14¾	16¼	18½	20¾	23	24½
Number of bolts	F	4	6	6	8	8	8	8	12	12	12	12	16	16	20	20
Size of bolts		¾	¾	¾	⅞	⅞	1	1	1	1⅛	1⅛	1¼	1¼	1¼	1¼	1¼
Diameter of bolt holes	J	⅞	⅞	⅞	1	1	1⅛	1⅛	1⅛	1¼	1¼	1⅜	1⅜	1⅜	1⅜	1⅜
Diameter of raised seat	K	3⅝	4¼	5¼	5¾	7	8⅝	9¾	11	12½	13⅝	14¾	17	19¼	21½	23
Diameter of spot bore	L	1⅝	1⅝	1⅝	1⅞	1⅞	2⅛	2⅛	2⅛	2⅜	2⅜	2⅝	2⅝	2⅝	2⅝	2⅝
Thickness of shoulder	N	½	9/16	⅝	⅞	1	1 1/16	1¼	1⅜	1 7/16	1½	1⅝	1 11/16	1⅞	2	2¼
Length of shoulder	P	2 1/16	2⅛	2 3/16	2¼	2⅜	2½	2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3 11/16

FIG. 20. High-Pressure Flanges, as adopted for the 59th St. Plant, New York.

joint. Attention is called to the fact that in flaring the end of the pipe the flared end becomes thinner than the pipe shell itself, especially after being faced; this will result



SIZE	A	1	1 1/2	2	2 1/2	3	3 1/2	4	4 1/2	5	6	7	8	9	10	11	12	13	14	15	16
THICKNESS OF SHELL	a	3/32	1/8	1/8	1/8	5/32	5/32	3/16	3/16	7/32	1/4	1/4	9/32	9/32	5/16	5/16	11/32	11/32	3/8	3/8	3/8
THICKNESS OF SHOULDER	b											1/2	9/16	9/16	5/8	5/8	11/16	11/16	3/4	3/4	3/4
OUTSIDE DIA. OF LOOSE FLANGE	B	4 1/4	5 1/4	6 1/4	7	7 3/4	8 3/4	9 1/2	10	10 3/4	11 3/4	13	14 1/4	15 3/4	16 3/4	18	19 1/4	20 1/2	22	23 1/4	24 1/2
DIA. OF BOLT CIRCLE	C	3 1/4	4 1/8	5	5 1/2	6 1/2	7	7 1/2	8	8 3/4	9 3/4	11	12 1/8	13 1/2	14 7/8	15 3/4	17	18 1/8	19 3/8	20 3/8	21 3/4
NO. OF BOLTS		4	6	6	6	6	6	6	8	8	8	10	12	12	12	14	16	16	16	18	20
SIZE OF BOLTS	d	1/2	1/2	5/8	5/8	3/4	3/4	3/4	3/4	3/4	7/8	7/8	7/8	1	1	1	1	1 1/8	1 1/8	1 1/8	1 1/8
DIA. OF BOLT HOLES	e	5/8	5/8	3/4	3/4	7/8	7/8	7/8	7/8	7/8	1	1	1	1 1/8	1 1/8	1 1/8	1 1/8	1 1/4	1 1/4	1 1/4	1 1/4
INSIDE DIA. OF LOOSE FLANGE	D	2 3/8	3	3 5/8	3 3/4	4 1/4	4 5/8	5 1/8	6	6 1/2	7 3/4	8 5/8	10	11 1/4	12 3/8	13 5/8	14 1/2	16	17 1/4	18 3/8	19 3/8
THICKNESS OF LOOSE FLANGE	f	5/8	3/4	3/4	7/8	7/8	1	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2
DIA. OF PIPE FLANGE	E	3	3 7/8	4	4 1/2	5 1/4	6	6 1/2	7	7 7/8	8 5/8	9 5/8	11 1/8	12 1/4	13 3/8	14 1/2	15 3/4	17	18 1/4	19 3/8	21 3/4
THICKNESS OF PIPE FLANGE	g	5/8	3/4	3/4	7/8	7/8	1	1	1 1/8	1 1/4	1 1/4	1 1/4	1 1/4	1 3/8	1 1/2	1 1/2	1 1/2	1 5/8	1 5/8	1 5/8	1 3/4
INSIDE DIA. OF GROOVE	F	1 5/8	2 3/8	2 7/8	3 3/8	4	4 1/2	5	5 1/2	6	7 1/4	8 1/4	9 1/2	10 1/2	11 3/4	12 3/4	13 5/8	15	16 1/4	17 3/4	18 3/4
OUTSIDE DIA. OF GROOVE	G	2 3/8	3 1/4	3 3/4	4 1/4	4 3/4	5 3/8	5 7/8	6 3/8	6 7/8	8 1/8	9 1/4	10 1/2	11 1/2	12 3/4	13 3/4	15	16 1/2	17 1/2	18 1/2	19 5/8
DEPTH OF GROOVE	h	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16
INSIDE DIA. OF TONGUE	H	1 13/16	2 5/16	2 13/16	3 3/16	3 15/16	4 7/16	4 15/16	5 7/16	5 15/16	7 3/16	8 3/16	9 7/16	10 3/16	11 11/16	12 11/16	13 11/16	14 15/16	16 3/16	17 3/16	18 7/16
OUTSIDE DIA. OF TONGUE	J	2 9/16	3 1/16	3 9/16	4 1/16	4 11/16	5 5/16	5 13/16	6 5/16	6 13/16	8 1/16	9 3/16	10 7/16	11 7/16	12 11/16	13 11/16	14 15/16	16 3/16	17 7/16	18 7/16	19 7/16
HEIGHT OF TONGUE	i	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
HEIGHT OF TONGUE IN LENS JOINT	j	9/32	9/32	9/32	9/32	9/32	9/32	9/32	9/32	9/32	9/32	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8
DIA. OF GASKET IN LENS JOINT		7/32	7/32	7/32	7/32	7/32	1/4	1/4	1/4	1/4	1/4	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16	5/16

The Engineering Magazine

FIG. 21. High-Pressure Flanges adopted as Standard by the Verein deutscher Ingenieure.

in an improper joint. To overcome this the loose flange abutting against the flared end should be slightly sloped, in order to give an even contact to the entire surface. A still better method is to reinforce or upset the pipe end before it is flared over. A

flange which complies with the above-mentioned condition is shown in Fig. 21; in this case a reinforcing ring is welded on the pipe, while a loose flange is so arranged that it

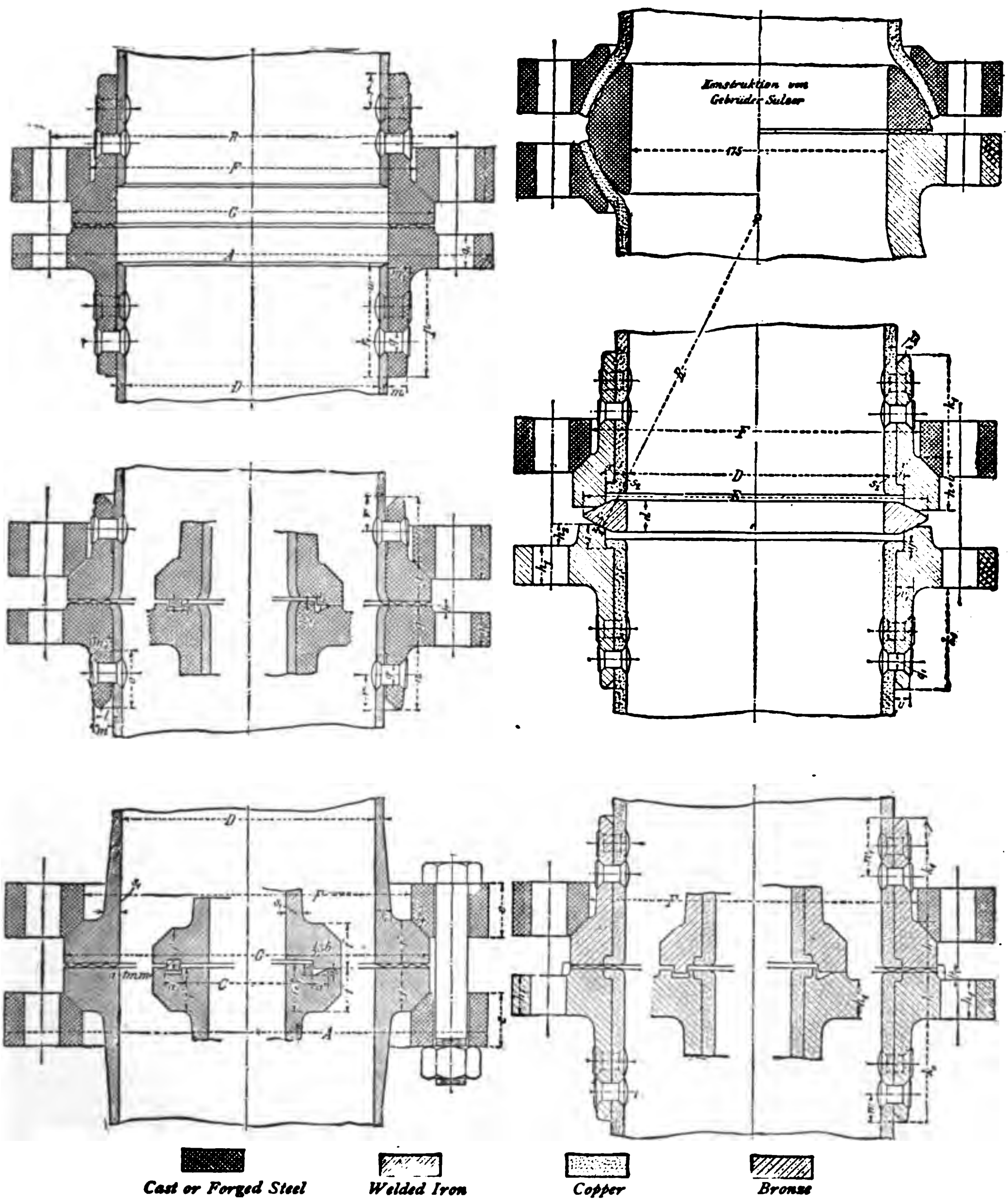


FIG. 22. Standard Flanges of the Verein deutscher Ingenieure.

shoulders on the above-mentioned ring on a forty-five degree bevel. This type of flange has been adopted for a pressure of 20 atmospheres (294 pounds) by the "Verein deutcher Ingenieure" in 1900. The accompanying table, Fig 21, is the standard adopted and

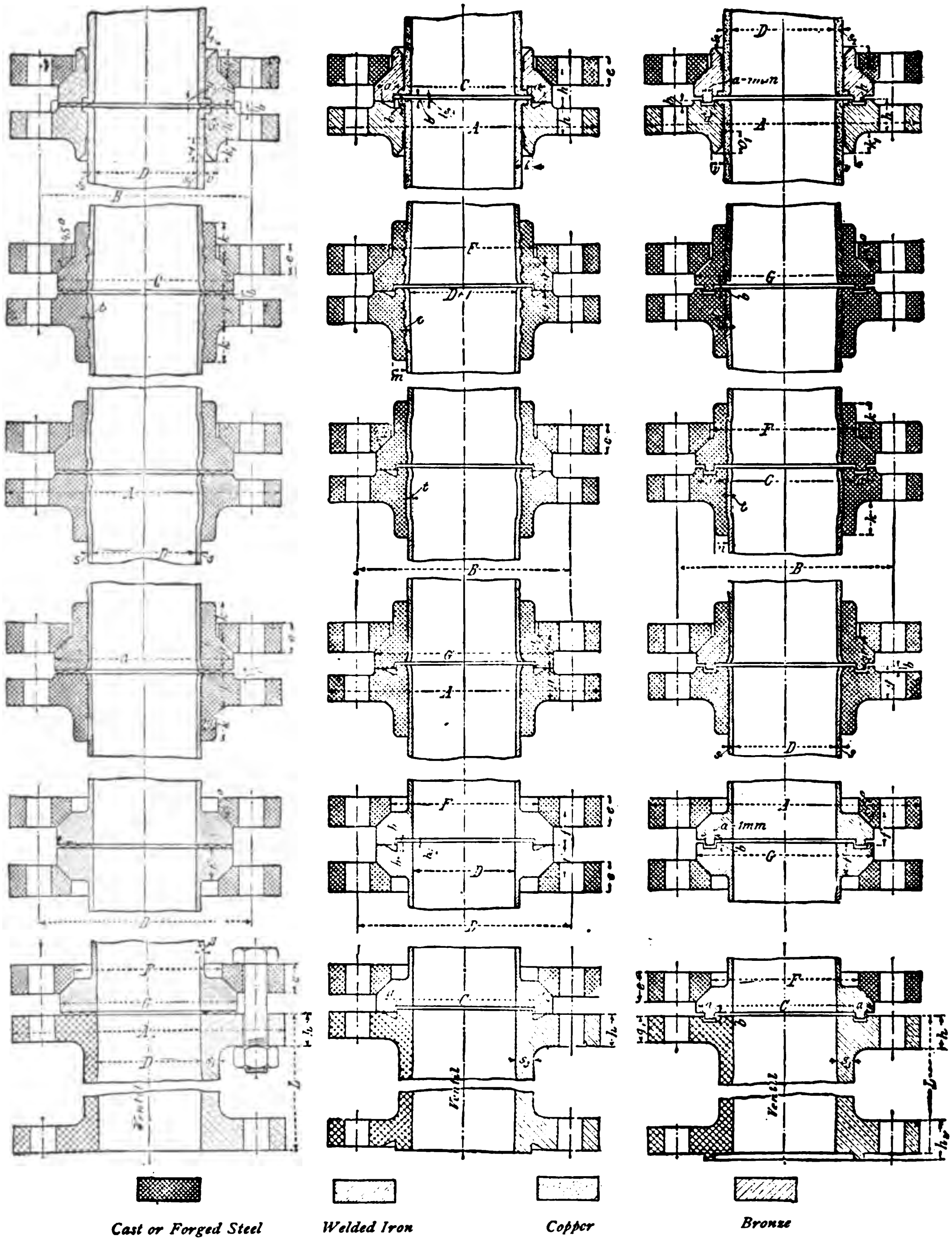
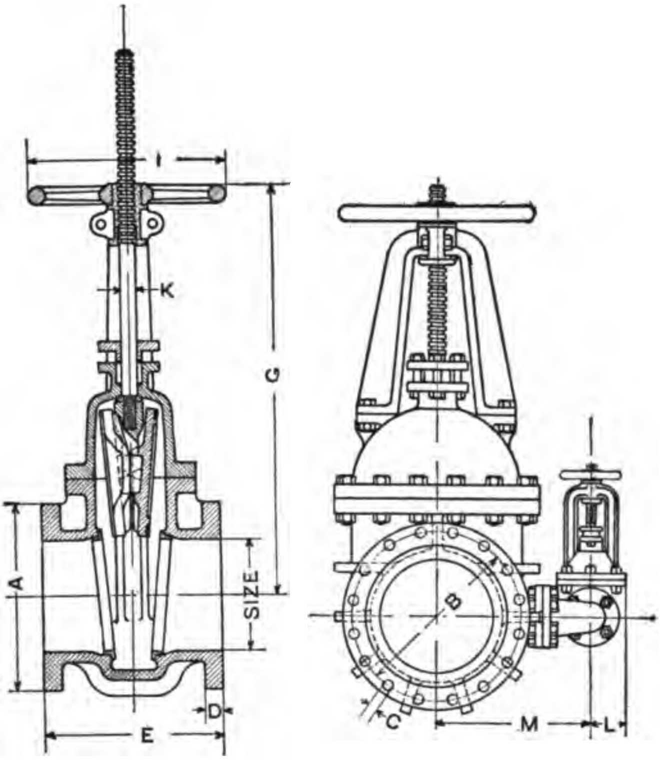


FIG. 23. Standard Flanges of the Verein deutscher Ingenieure.

has been converted by the author from the metric system to read in inches and the fractional parts of an inch. All dimensions have been slightly increased over what the converted figure would be; number and size of bolt have not been changed.



Valve without by-pass. Valves below 8" are made without Ribs. Valves 8" and above are ribbed.

SIZE	1½	2	2½	3	4	5	6	7	8	10	12	14	15	16	18	20	22	24	28
A	6	6½	7¼	8¼	10	11	12½	14	15	17½	20	22½	23½	25	27	29½	31½	34	38½
D	¾	⅞	1	1⅛	1¼	1¼	1⅜	1½	1¾	1⅞	2	2⅛	2¼	2¼	2⅜	2½	2⅝	2¾	3
E	7	8¼	9	9½	11	11¾	13	15	20½	22¾	23¾	26	26¼	32					
F							19	20	20½	22¾	23¾	26	26¼	32	33¼	35¼	37¾	40	40
G	12	15¼	16½	18¼	23	27¼	30	33¼	37	42	49	54	57½	61½	69	74	82½	90	97½
H	14½	18½	20½	22½	28¼	34¼	38	42	47	54	63¼	70	74¾	79½	89½	96½	107½	117	128
I	6	7½	9	9	12	15	15	15	18	18	21	21	27	27	32	32	36	Gear	Gear
K	¾	⅞	1	1	1⅛	1¼	1¼	1¼	1½	1½	1¾	1¾	2	2	2¼	2¼	2½	2½	3¼
L									2⅞	2⅞	3¼	3¼	3½	5	5	5	5¾	5¾	6½
M									16	17	19¾	20½	22	24	25½	26	26¼	26¾	32¾
N									1½	1½	2	2	2	3	3	3	4	4	5
O	13	14	12	14	17	12	13	16	18	22	26	29	32	34	38	42	47	153	216

"N" size of by-pass. "O" No. turns to open.
The bore of all gates 14 inches and larger is made to suit the inside dimensions of O. D. pipe. For standard flange dimensions see ;

FIG. 24. Taper Seat Gate Valve, 250 lbs. working pressure, (Pittsburg Valve, F. and C. Co).

A number of flanges that have been adopted by the above-mentioned society is given in Figs. 22 and 23. From these designs a type to suit any condition may be selected, since they are suitable for high and low pressure, both for steam and water

pipes. All joints are provided with loose flanges similar to the table given in Fig. 21. One benefit of these loose flanges is the greater variety of angles which may be obtained, for the bolt holes always match.

The pipe flanges, according to good practice, should be provided with a number of bolt holes which is a multiple of four, in order to shift cast fittings, should it be required, 90°; some multiples of four may be shifted 45° and still match the bolt holes. Some power plant designers claim this practice to be indispensable, but the author does not agree with them, although it may be a good practice. All pipes above 3 inches diameter should be flanged, while below 3 inches screwed fittings may be used.

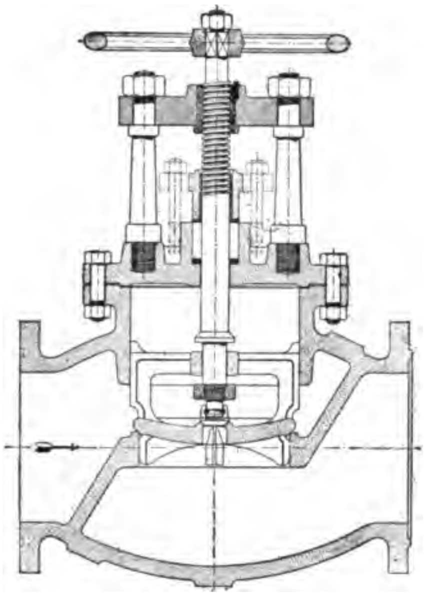


FIG. 25. Superheated Steam Valve with By-pass.

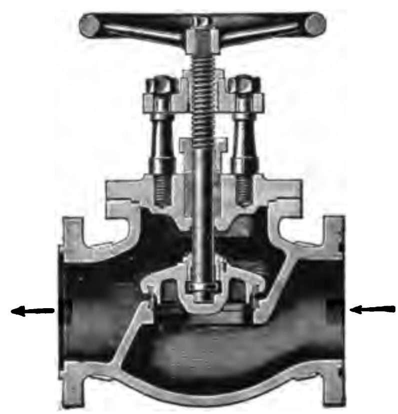
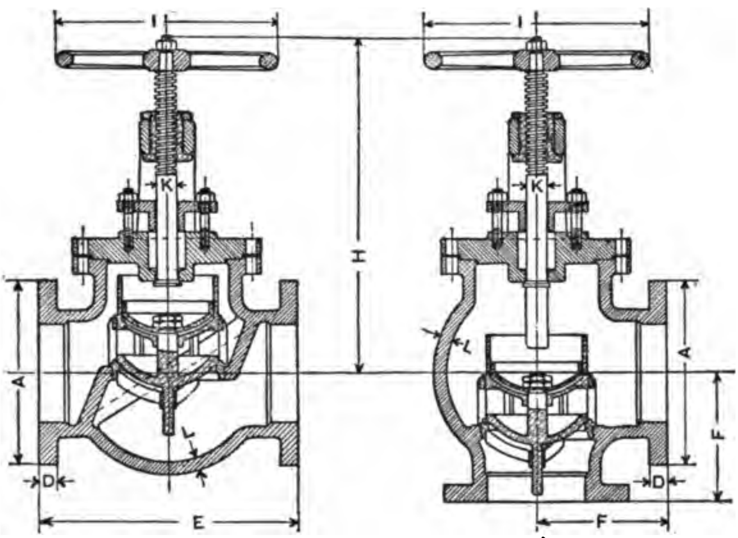


FIG. 26. High-Pressure Superheated Steam Globe Valve.

To a great extent in American practice ground joints are used which, when properly made, are undoubtedly superior to any other, while in Europe gaskets are used almost exclusively. In using ground joints a straight face is preferable, while in employing gaskets either straight face, male and female or tongue and groove joints may be used. Gaskets may be made of corrugated copper rings, an improved type of which is one which has asbestos rings placed in the corrugation. Corrugated gaskets may also be made of soft steel. Another gasket is made up of copper wire cloth or ring; the latter gaskets are especially adapted to a tongue and grooved joint.

Valves. — The valves employed for the main steam pipes are of two types, either globe or gate valve. American and English practices favor gate valves, while on the Continent globe valves are used exclusively. This is due to the fact that the former

are cheaper, while the latter are more suitable for a high degree of superheated steam. When specifying valves for superheated steam, care should be taken that no soft composition is used. For instance, in a globe valve the disc and seat should be made of a hard alloy, such as gun metal, nickel steel, etc.; also the stuffing-box gland, so far as it will come in contact with the steam, should be made of the same material; the



SIZE.	4	5	6	7	8	10
A	10	11	$12\frac{1}{2}$	14	15	$17\frac{1}{2}$
D	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{7}{8}$
E	12	$13\frac{1}{4}$	17	20	21	25
F	6	$6\frac{3}{4}$	$8\frac{1}{2}$	10	$10\frac{1}{2}$	$12\frac{1}{2}$
H	$17\frac{3}{4}$	$21\frac{1}{2}$	$22\frac{5}{8}$	$25\frac{1}{2}$	$27\frac{1}{4}$	$32\frac{3}{4}$
I	9	12	15	15	18	21
K	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2

FIG. 27. Non-Return Valve for 250 lbs. Working Pressure (Pittsburg Valve, F. & C. Co.)

same may be said in specifying a gate valve so far as pertains to the seat, gate and gland. Fig. 24 represents a well-designed gate valve, as manufactured by the Pittsburg Valve, Foundry and Construction Company, while Figs. 25 and 26 show typical continental globe valves. In the latter the seat and body are made of one piece, while the disc itself is made of the same metal as the body, namely, cast iron. It will be noticed that the disc is drilled for a by-pass valve operated by the main spindle; by-pass is used both for globe and gate valves of sizes above 8 inches or 10 inches.

In using globe valves they should be so placed that the pressure is under the disc. Attention is called to Fig. 25, in which an arrow indicates steam entering on the top of disc; the disadvantage of this design is that to pack a valve the entire line must be shut down, or if the spindle should break the disc will fall on the seat and act as a check valve. A globe valve should never be placed in a vertical position in a steam line, unless proper provision be made for drips, but should be installed at a slight angle off the horizontal (enough to keep the stuffing box dry) so that a free and unobstructed passage is left for the flow of water of condensation. No steam valves should be placed with the stem looking down, so that there will be no place for the collection of water around the stuffing box.

All valves should be so placed as to be readily accessible, either from the floor or from a gallery. Frequently this feature is overlooked and ladders have to be used, which seriously hampers the successful operation of the plant. Wherever it is impossible to so place the valves, bevel gearing and rod or an endless chain may be used.

Besides those described above, there are a number of other valves, such as automatic stop valves,

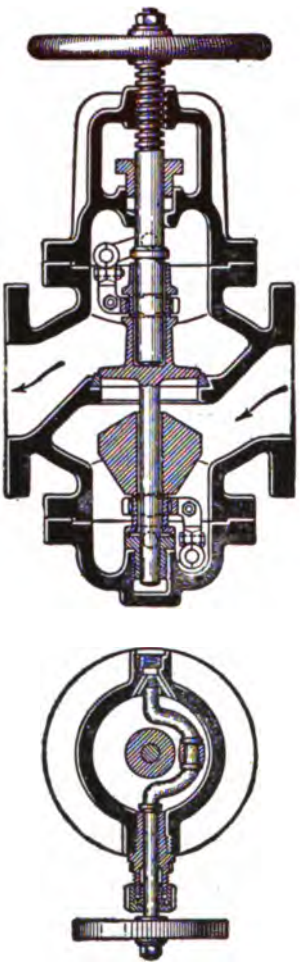


Fig. 28.
Automatic Closing Valve.

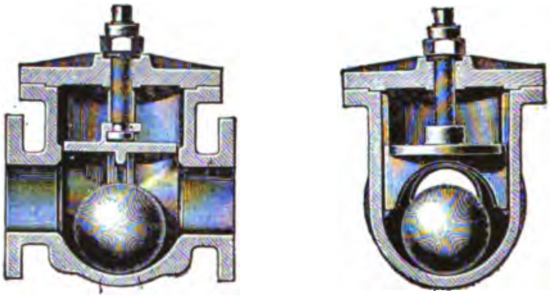


Fig. 29. Automatic Closing Valve (System Schäffer and Budenburg), acts in both directions of flow of steam.

pressure-reducing valves, etc., which come into consideration in designing the main steam piping. In the steam connection, between the boiler and the boiler header, and directly on the boiler nozzle, a non-return valve should be placed, so that in case of any serious falls in pressure in a particular boiler no steam from the header can return to the boiler, the valve opening automatically when the affected boiler again regains its normal pressure. A valve of this character is shown in Fig. 27; this valve

will operate in one direction only, while a valve closing in both directions of the flow of steam, so that in case of a fracture either in the main steam line or in the boiler itself, the increased velocity of the steam would close the valve, as seen in Fig. 29. Provision is made to regulate for the required velocity; another automatic closing valve, built either for angle or straight, for vertical or horizontal position, is given in Fig. 28. It is the Hubner & Mayer patent of Vienna and is on the market both in England and America.

In large power plants it might be admissible to operate the main valves from one central point. This may serve especially in case of an accident. The valves may be operated either by electric motors, air, steam or water pressure.

In many power plants where the auxiliaries are steam driven, reducing valves are placed in the steam line to reduce from a high pressure to a lower one suitable for the

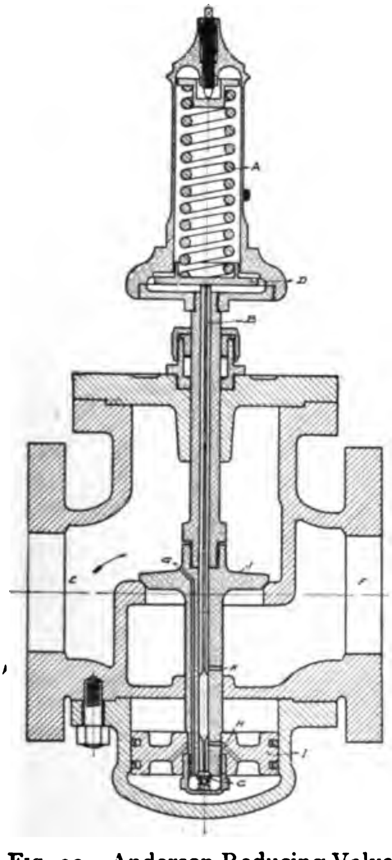


FIG. 30. Anderson Reducing Valve.

FIG. 31. Stratton Separator.

machinery (Fig. 30). The reason for this reduction in pressure is that many manufacturers have not designed auxiliaries suitable for the high pressure used in the main engines. However, "modern" auxiliaries are being designed for high pressure, thus

doing away with the necessity of employing a reducing valve and separate pipe line, and increasing the convenience of operation.

Most high-pressure reducing valves are of the spring type and are adjusted by means of a set screw, which increases or decreases the tension of the spring. It is natural that a spring under a constant stress should weaken, thereby changing the pressure at the delivery side of the valve; this must be attended to during operation. In selecting a reducing valve, one should be decided upon that has few parts and is simple in design; there are a number of these on the market.

Drip System. — The drip system in a saturated steam plant is more important than when superheated steam is used, since superheated steam, especially with a high degree of temperature, contains little or no water, while with saturated steam a considerable amount of water is carried from the boiler, and makes it necessary to employ separators, or so-called "water catchers." These water catchers are designed for the purpose of removing water from the steam. Some designs are shown in the

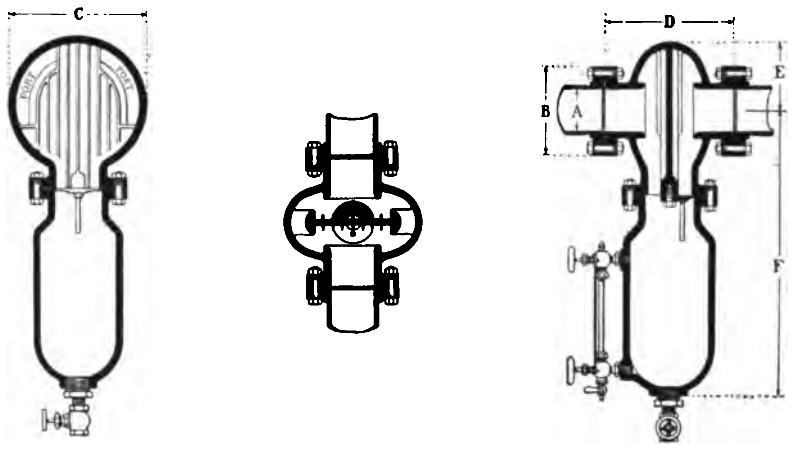


FIG. 32. Cochrane Horizontal Separators.

accompanying illustration. Other types are of a combined system, acting as a water catcher and steam collector; these are large bodies, usually made of wrought iron or steel plates and are used exclusively in plants in which reciprocating engines are installed. This apparatus should be large enough to hold enough steam to reduce the vibration of the pipes, which is caused by the sudden cut-off in the valve motion; such steam reservoirs should be employed both for saturated and superheated steam. The steady flow of steam to a turbine eliminates the necessity for these reservoirs.

Where superheated steam is used the pipe lines should be provided with a drip system. It is claimed frequently in using superheated steam that no drip system need be employed. This is an error, as there is no superheated steam conveyed but what there may be more or less condensation in the pipe. There should be, at least, one drip provided directly before the steam enters the prime mover. This may be

accomplished by inserting a tee in the line with the outlet looking downward, thus forming a pocket from which a small drip pipe is connected.

High-pressure drip connections should be run through traps to a receiving tank or heater from which the water may be fed to the boiler. As all traps are troublesome and sooner or later get out of commission, it is necessary to by-pass same to make repairs conveniently. The main steam-pipe line and valves have also to be provided with a bleeder system, so that before turning steam upon a cold pipe the water in the line may be drawn off. As a number of drips are connected to one trap, this bleeder line should run directly to a tank or some other system of water disposal. Special attention is called to the above, since frequently the mistake is made of connecting this low-pressure bleeder system to the high-pressure drip, the result of which is that the high-pressure drip will back up into the main steam piping. In fact, the design of an efficient drip system is one of the most difficult problems. Many power plant designers are of the opinion that such small piping should not be put on paper, but should be left to the erecter. This might be well for power plants in which the increased consumption of water and coal, due to improper draining, is not a factor. The author has experienced, in some cases, more difficulty with the drip system than with the main steam piping.

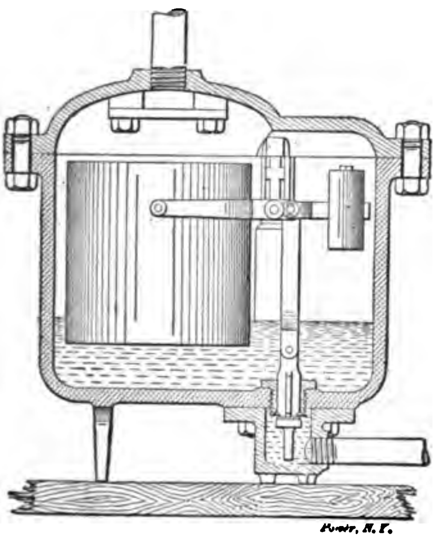


FIG. 33. Thoen Steam Trap.

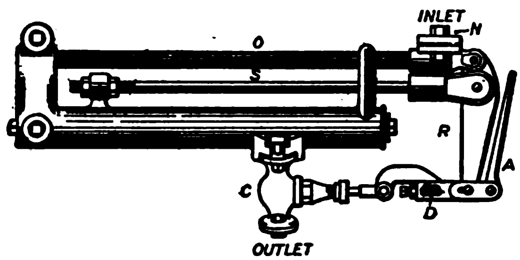


FIG. 34. Columbia Expansion Trap.

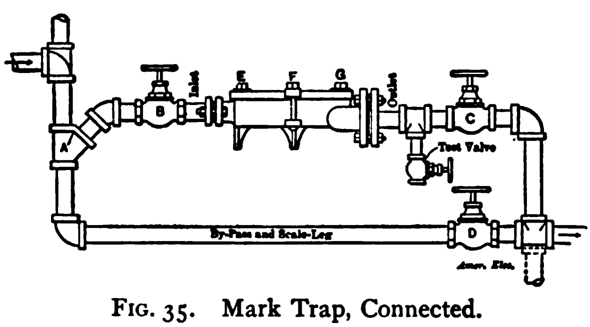


FIG. 35. Mark Trap, Connected.

There are drip systems in practical use which return the water of condensation directly to the boiler. These systems, however, require special provisions; for instance, the Holly gravity return system, which operates as follows: The drip pipes from the various points are led to a receiver, which is placed at a point below the lowest

drainage outlet, usually about the central point of the plant. A riser pipe from the receiver reaches to the discharge chamber thirty feet or more above the boiler water line, and a return pipe connects the discharge chamber to the boiler at some point below the water line. The water of condensation is carried by the movement of steam to

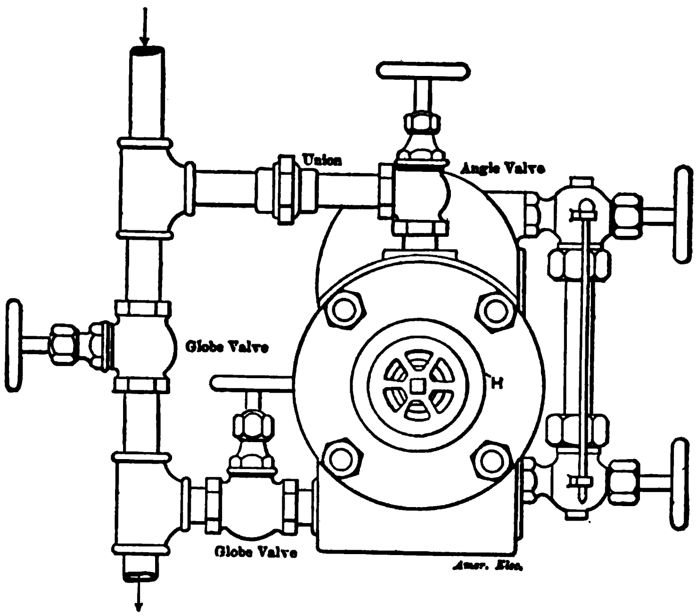


FIG. 36. Cookson Trap, Connected.

the discharge chamber by entrainment, and care is taken that the altitude of the discharge chamber is great enough to permit of the accumulation of sufficient head in the return line to restore the pressure loss under all conditions, and to make the return to the boiler. The system is kept free from air and the riser action is accel-

TABLE II.—EXPERIMENTS ON THE LOSS OF HEAT FROM BARE STEAM PIPES.

NAME OF EXPERIMENTER.	Approximate Duration in Hours.	Number of Tests Averaged.	Size of Pipe.	Square Feet of Pipe Surface.	Pressure of Steam.	Temperature of Steam.	Temperature of Air.	Difference of Temperatures.	Lbs. of Steam Condensed per Sq. Ft. per hour.	B.T.U. per Sq. Ft. per Hour per 1°.
Barrus	3.3	7	2″	63.57	82.2	325.2	56.6	268.6	.915	3.01
Barrus	4.3	7	2″	63.92	149.6	365.4	63.2	302.2	1.150	3.25
Barrus	2.7	3	10″	98.33	149.3	365.3	73.6	291.7	1.085	3.18
Hudson-Beare	—	1	3.53*	8.13	135.0	358.0	67.0	291.0	1.050	3.10
130 pounds	48	1	2″	50.66	128.7	354.7	80.1	274.6	.994	3.13
Jacobus	—	1	2″	7.63	53.4	300.8	71.2	229.6	.707	2.78
Brill	1	4	8″	135.4	110.5	344.5	75.5	269.0	.834	2.71

* Actual outside diameter.

erated by the venting of a small amount of vapor from the discharge chamber, this being usually discharged into the feed-water heater.

Pipe Covering. — What the condensation in bare pipes amounts to is fully treated by Paulding in "Steam in Covered and Bare Pipes." Table II, computed by the above author (see page 212) showing the results obtained by various experimenters with different sizes of pipes and different pressures. For ordinary calculation an average of three B. T. U. per hour per square foot of exposed surface may be assumed.

To calculate the financial loss due to using a bare pipe over that of a covered one, the following formulas may be used, assuming a short ton (2,000 pounds); if a long ton is used the constant is 2,240 pounds.

$$\text{Cost per annum of steam condensed} = \frac{3\,A\,(t - t_1)\,N \times C}{965.8 \times 2{,}000\,E}$$

in which

A = Area of exposed pipe surface in square feet.
t = Temperature Fahr. of steam.
t_1 = Average temperature Fahr. of surrounding water.
N = Hours per annum steam is in the pipe line.
E = Evaporation from and at 212° Fahr. per lb. of coal.
C = Cost of coal and handling, per ton.

By using this formula the percentage saved by the covering is ascertained.

In order to reduce the condensation in the pipe, it is necessary to give same a proper insulating covering. Pipe coverings are valued by the percentage of saving in condensation over that which occurs in a bare pipe; they range from 65 per cent to 85 per cent and higher. There are many varieties on the market; the material used ranges from an earthy substance up to silk.

All pipe covering should be non-combustible; some of the materials used in covering are as follows: hair felt, magnesia, asbestos, silk, Kieselguhr and similar earthy substances. The covering frequently used in American practice consists of 85 per cent carbonate of magnesia mixed with 15 per cent of asbestos. This covering is applied to the pipe in molded sections and usually in two layers, the seams of which are staggered and filled with magnesia plaster. The thickness of these coverings depends on the size of pipe, although the radiation per square foot of surface is the same in a small as in a large pipe. The practice, however, is, in a first-class covering, to employ 2-inch covering up to 2-inch pipe, 2½-inch up to 8-inch, and 3-inch on any size above. The sections are bound to the pipe by means of galvanized iron wire or netting, over which is wrapped a coat of rosin-sized paper followed by eight-ounce canvas securely sewed on.

There are in England and America other efficient systems of pipe covering in use; for instance, the asbestos air-cell covering, which consists of several layers of corrugated asbestos sheets, making a laminated covering in which the corrugations form an air space.

On the Continent of Europe, Kieselguhr is used to a great extent. It is a pulverized earthy substance, and before it is applied to the pipes it is made into a paste and is then plastered in several courses on the pipes and sewed in with canvas. With this covering when organic bodies are mixed with the paste, and after steam is turned into the pipes, these organic particles shrink, leaving numerous small air spaces and increasing the efficiency of the covering. Another plan is to wrap either the plain Kieselguhr, or the Kieselguhr with organic particles, in raw silk.

Another efficient covering is one in which an air space is employed. A system of this kind is the Pasquay. The covering consists of perforated iron furred out from the pipe, over which raw silk is wrapped, and a second jacket in a similar way is placed upon the first one. The efficiency of this and the Kieselguhr covering exceeds 85 per cent.

In a paper by Mr. H. G. Stott, entitled "Steam Pipe Covering and its Relation to Station Economy," read before the Association of Edison Illuminating Companies in 1902, this subject was very thoroughly covered by Mr. Stott, who conducted tests to determine the most efficient type and thickness of covering, before awarding the contract for the Manhattan Elevated Railroad station.

The method adopted consisted in coupling up about 200 feet of two-inch iron pipe and mounting same on wooden horses about three and one-half feet from the floor, the three lines of pipe being approximately four feet apart and four feet from the nearest wall, in order to avoid any errors due to heat convection and radiation. Sections 15 feet in length were marked off on the straight portions of the pipe, and so arranged as not to include any pipe couplings or bends; two feet from each end of each section heavy potential wires were soldered on to the pipe, and at the extreme ends of the pipe 1,500,000 cm. copper insulated cables were soldered on, the openings in the pipe having been previously closed by means of a standard coupling and plug. One of these cables ran direct to one terminal of a 250-KW. 250-volt steam-driven, direct-coupled exciter, which was solely devoted to furnishing current for the test, and had its voltage variable within wide limits, so as to furnish any current up to 1,500 amperes. The cable connected to the other end of the pipe was then connected to three ammeter shunts in series, in order to enable the readings to be easily checked, after which it was carried through a circuit breaker and switch to the other exciter terminal. The pipe covering test was carried on in a vault in which there was no source of heat and no possibility of drafts of air, and arranged so that the section in which the test was being carried on could be locked up in order to prevent interference.

Altogether twenty-one tests were made of various constructions of coverings. The table on following page, arranged in order of efficiency, shows the best results obtained:

Frequently the pipe covering after being canvas jacketed is painted. This paint should be fireproof and of light color, as light colors are not heat absorbents and will thereby reduce radiation. It is a good scheme to paint pipes for different purposes of various colors, so that they may be readily known, thereby enhancing the convenience of operation.

TABLE III.

COVERING.	B.T.U. loss per sq. ft. at 160 lbs. Pressure.	Per cent. Heat saved by Covering.
"Remanit" (carbonized silk) wrapped	1.708	86.9
85 per cent Magnesia, sectional	2.060	84.2
Solid Cork, sectional	2.170	83.3
Laminated Asbestos Cork, sectional	2.395	81.6
Asbestos Air Cell (intended), sectional ("Imperial")	2.465	81.0
Asbestos Sponge Felted, sectional	2.683	79.4
"Asbestocell" (Radial), sectional	2.920	77.5
Asbestos Air Cell (Long), sectional	3.015	76.8
Bare Pipe (from outside tests)	13.000	—

Boiler Feed Piping.— The size of boiler feed pipes is usually chosen for a velocity of from 300 to 400 feet per minute. The entire feed pipes are made of extra heavy material. The main pipes are made of cast or wrought iron. To secure a uniform standard, the flanges should be of the same type as that of the main steam piping. The main line should be so laid out as to have either a double-header or ring system, so as to supply any boiler in case of emergency; sufficient valves should be inserted, so as easily to cut out defective sections. As the temperature of the boiler feed water is high, sometimes exceeding 212° Fahr., dependent upon the equipment of the plant, if heaters or economizers are installed provision must be made to take up the expansion by means of long flexible bends.

FIG. 37. High-Pressure Check Valve for Boiler Feed Water.

The branch pipes to the boilers are generally supplied by the boiler manufacturer. These pipes are, in America, made of extra heavy brass, while on the Continent of Europe copper is frequently employed. The practice of using brass and copper arises from the flexibility of those metals and their ability more readily to take up such shocks as are received from the pumps, or from shutting down valves. Copper has been used on the Continent of Europe on account of its high polish, not because of appearance, but to prevent radiation.

All pipes, such as are not polished, as above mentioned, should be carefully covered, as described under high-pressure steam piping.

Check and hand valves should be placed in each branch line, so that the water cannot return from the boiler to the feed line should the boiler pressure increase over that in the feed main. The check valve should be placed between two cut-off valves to facilitate repairs.

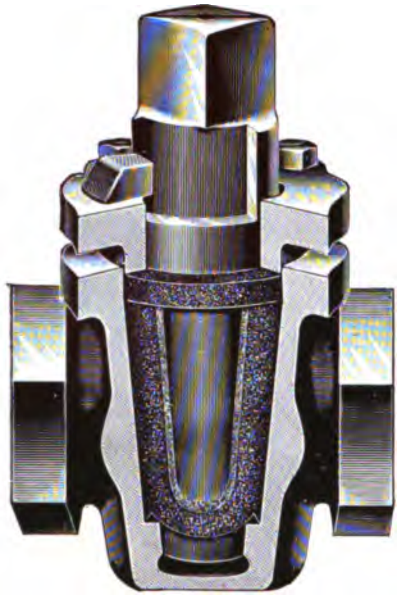


FIG. 38. Fairbanks Asbestos Packed Blow-Off Cock.

In order to maintain an equal pressure, the main feed pipe is connected by means of a small pipe to a pressure regulator, inserted in the steam pipe to the boiler feed pumps. Should the pressure increase above that required, the steam supply will be automatically cut off and the pump slowed down, while when additional water is required the pumps start again automatically.

Boiler Blow-off Piping. — Usually each boiler is provided with two blow-off pipes, generally $2\frac{1}{2}$ inches in diameter. On some types of boilers these pipes are located directly in the flue gas passage and it is, therefore, frequently necessary to protect them by running them through a pipe. The blow-off pipe should be made of extra heavy material, capable of withstanding 175 to 200 pounds working pressure. In order that the blow-off valve may be packed while the boiler is in operation, an additional valve should be used. These valves are of different types, one being an asbestos packed cock, the other a specially designed blow-off valve. In selecting a blow-off valve care should be

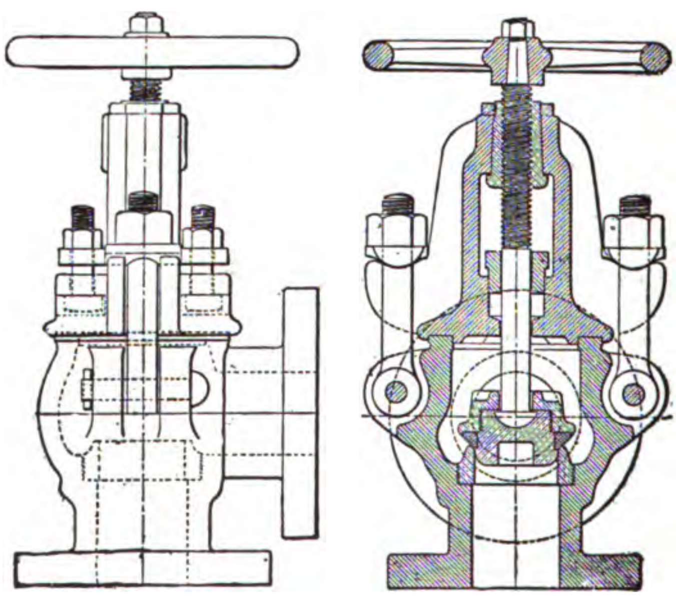


FIG. 39. Morris Blow-Off Valve.

taken that there are no projections or other places for the accumulation of mud or other boiler sediment, so that these valves may not stick, but readily come to a perfect seat.

A number of boilers may be connected to one common blow-off header; and since generally but one boiler is blown down at a time, the diameter of this header may be three inches or four inches. All branches should connect to the header by means of a "Y" to minimize resistance due to mud, etc. The blow-off line should be made of extra heavy wrought iron with provision made for expansion.

The size of blow-off tank depends on the number of boilers connected to same. In prominent plants, where twelve to eighteen 600-horse-power boilers are connected to one tank, the tank may be from five feet to six feet diameter and from six feet to eight feet high, and made of rolled steel, while in smaller plants usually a horizontal tank three feet by six feet is used.

The blow-off tank should be provided with an overflow pipe and a vent; this latter may discharge either directly to the roof or to the atmospheric exhaust pipe, in some instances it is connected to the auxiliary exhaust and discharge through the heater.

LOW-PRESSURE PIPING.

Under the heading of low-pressure pipes we may consider the main exhaust, auxiliary exhaust and their drain systems, circulating water, vacuum and hot well suc-

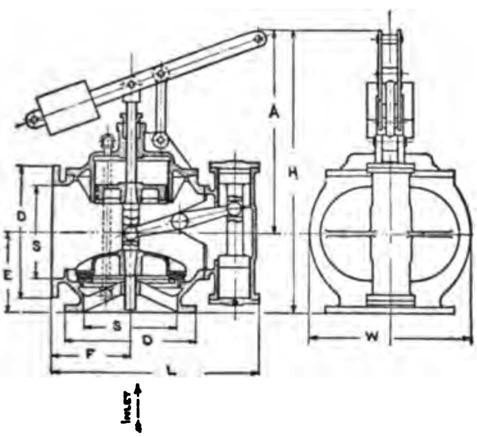


FIG. 1. Blake Angle Automatic Back-Pressure Valve.

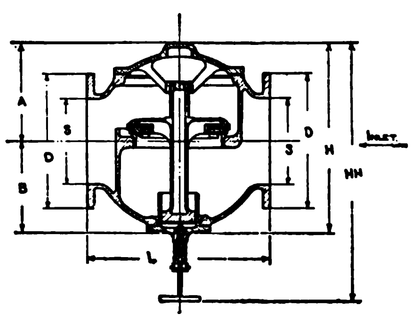


FIG. 2. Blake Horizontal Automatic Exhaust Relief Valve.

tion and discharge, suction of the boiler feed pumps, suction and discharge of house pump which supplies tanks, toilets, fire line, etc.

Size of Exhaust Pipes. — In calculating the size of the atmospheric exhaust pipes, a velocity of from 5,000 to 6,000 feet is used, while up to the condenser a velocity up to 30,000 feet is frequently chosen. This high velocity is due to the fact that, for instance, a pound of steam under a 24-inch vacuum contains 118 cubic feet; with three pounds gauge pressure a pound of steam contains 21½ cubic feet; it is, therefore, self-evident that steam under vacuum being vastly rarer than steam above atmospheric pressure the friction is so slight as not to be taken into account.

Material. — All pipes under vacuum should be absolutely tight. For this reason cast-iron pipe is usually adopted. Whenever long runs of pipe under a vacuum are necessary, rolled steel should be used; all rivets and joints have to be securely caulked to avoid any leakage. A less frequent practice is to use spiral riveted galvanized pipe.

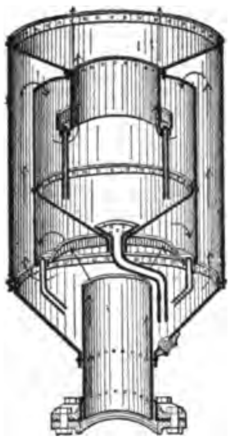


FIG. 3. Cyclone Exhaust Head.

The atmospheric exhaust, however, may be of spiral riveted or other light steel pipe, as it is not subjected to much stress and leakage is not considerable; and as these pipes are flexible, expansion is easily cared for, while in the case of cast-iron pipes, expansion joints may have to be used.

Fittings. — These expansion joints may be either of the slip-joint or corrugated copper type, such as the Wainwright. These joints may be employed in low-pressure piping, but should never be used with high pressure.

Each unit should be separately valved (either by an automatic exhaust relief valve or a cut-off gate valve) in the connections to the main exhaust, so that it may be cut out without interfering with the operation of the rest of the plant. The exhaust riser should be provided with an exhaust head, which acts as a muffler and at the same time collects the water of condensation, which would be a nuisance to the surroundings.

Flanges for low-pressure pipes should not ordinarily be of special design, but should

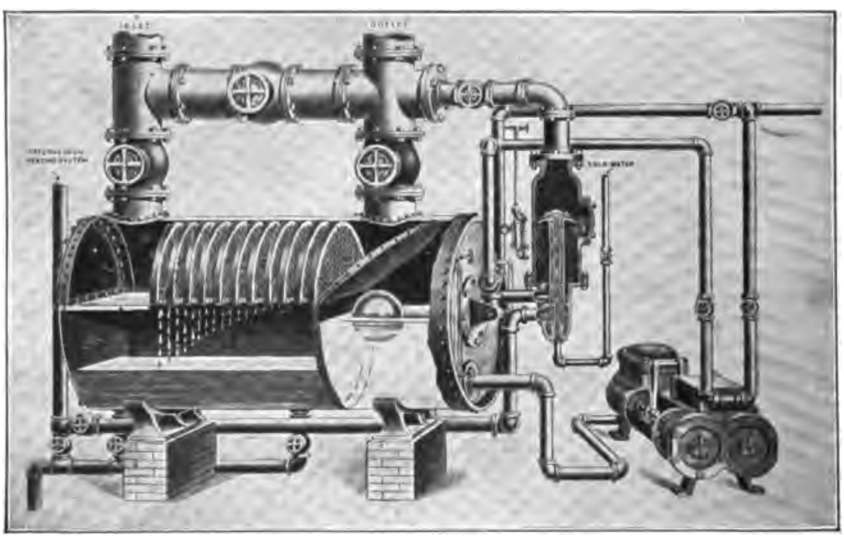


FIG. 4. "Utility" Oil Extractor and Feed-Water Heater.

be standard. Bolt or screwed flanges may be used on large pipes, while on small pipes screwed fittings are more convenient and cheaper.

FIG. 5. Capacity in Gallons per Minute Discharged at Velocities in Feet per Second, from 8 to 15; also Friction Head in Feet per 100-Foot Length of Pipe.

Dia. Pipe	1-inch		2-inch		3-inch		4-inch		5-inch		6-inch		7-inch		8-inch		10-inch		Dia. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
8	19.58	24.5	78.32	12.2	176.24	8.16	314.12	6.12	489.68	4.90	705.64	4.08	959.44	3.49	1258.4	3.06	1958.4	2.45	8
8½	20.80	27.4	83.23	13.7	187.25	9.15	333.75	6.86	520.61	5.49	749.01	4.57	1019.4	3.92	1331.5	3.43	2080.8	2.74	8½
9	22.03	30.5	88.11	15.2	198.27	10.1	352.26	7.64	550 89	6.11	793.72	5.09	1079 4	4.36	1410.1	3 82	2203.2	3.05	9
9½	23.25	33.8	93.00	16.9	209.24	11.2	371.90	8.46	581.25	6.77	837.06	5.61	1139.4	4.83	1488.0	4.23	2325.6	3.38	9½
10	24.48	37.3	97.90	18.6	220.30	12.4	391.40	9.33	612.10	7.46	881.80	6.21	1199.3	5 33	1566.8	4.66	2448.0	3.73	10
10½	25.70	40.9	102.80	20.4	231.31	13.6	411.05	10.2	642.43	8.19	925.20	6.82	1259.3	5.84	1645.8	5.22	2570.8	4.09	10½
11	26.92	44.7	107.69	22.3	242.33	14 9	430.54	11.1	673.31	8.95	969.88	7.45	1319.2	6.39	1723.5	5.59	2692.8	4.47	11
11½	28.15	48.7	112.58	24.3	253.34	16.2	450.20	12.1	703.62	9.74	1013.3	8.11	1379.2	6.95	1801.5	6.08	2815.2	4.87	11½
12	29.37	52.8	117.48	26.4	264.36	17.6	470.68	13.2	734.52	10.5	1057.9	8.80	1439.2	7.54	1880.2	6.60	2937.6	5.28	12
13	31.82	61.5	127.27	30.7	286.39	20.5	509.82	15.3	795.73	12.8	1145.0	10.2	1559 1	8.79	2036.8	7.90	3182.4	6.15	13
14	34.27	71.0	137.06	35.5	308.42	23.7	548.96	17.7	856.94	14.2	1233.1	11.8	1679.0	10.1	2193.5	8.87	3427.2	7.10	14
15	36.72	81.0	146.85	40.5	330.45	2.70	587.10	20.3	918.15	16.2	1321.2	13.5	1799.0	11.6	2350.2	10.1	3672.0	8.10	15
Dia. Pipe	12-inch		15-inch		18-inch		20-inch		24-inch		30-inch		36-inch		42-inch		48-inch		Dia. Pipe
Velocity	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Capacity	Friction	Velocity
8	2820.1	2.08																	
8½	2996.3	2.33	4688.1	1.82	6741.9	1.52	8823.6	1.37	11985.	1.14	18725.	.915	26967.	.760	36704.	.653	47942.	.571	8½
9	3172.7	2.60	4957.7	2.04	7138.1	1.70	8812.	1.53	12690.	1.27	19827.	1.01	28554.	.847	38863.	.728	50762.	.636	9
9½	3348.9	2.88	5232.1	2.25	7534.8	1.88	9302.6	1.69	13395.	1.40	20928.	1.12	30140.	.938	41022.	.806	53582.	.694	9½
10	3525.2	3.17	5508 4	2.50	7931.0	2.07	9792.	1.87	14100.	1.55	22030.	1.24	31726.	1.03	43181.	.888	56403.	.778	10
10½	3701.4	3.48	5783.4	2.78	8328.8	2.27	10281.	2.05	14805.	1.70	23131.	1.36	33313.	1.13	45340.	.975	59223.	.851	10½
11	3877.7	3.80	6058.2	2.98	8724.9	2.48	10771.	2.24	15510.	1.86	24233.	1.49	34899.	1.16	47499.	1.06	62043.	.930	11
11½	4053.8	4.14	6334.6	3.25	9121.7	2.70	11258.	2.43	16215.	2.03	25338.	1.62	36485.	1.35	49658.	1.16	64863.	1.00	11
12	4230.2	4.49	6609.9	3.52	9517.8	2.93	11750.	2.64	16920.	2.20	26436.	1.76	38072.	1.46	51817.	1.26	67683.	1.10	12
13	4582.8	5.23	7160.6	4.10	10310.	3.42	12729.	3.08	18330.	2.56	28639.	2.05	41244.	1.70	56135.	1.46	73324.	1.28	13
14	4935.4	6.03	7711.4	4.73	11104.	3.98	13708.	3.55	19740.	2.95	30842.	2.37	44417.	1.97	60453.	1.69	78964.	1.48	14
15	5287.8	6.89	8262.1	5.40	11897.	4.50	14688.	4.05	21150.	3.37	33045.	2.70	47590.	2.24	64771.	1.98	84604.	1.69	15

Drips. —The entire atmospheric exhaust line should be properly drained by means of traps or water seals. The water of condensation, if from a turbine, may be returned directly to a feed-water tank, while if from a reciprocating engine it must be wasted or first separated from the oil, either by means of an oil extractor or a water filter. Where the exhaust steam, from a reciprocating engine, is used for heating, an oil extractor should be placed in the line. One of the most prominent types of grease extractors is shown in Fig. 4.

Circulating Water Piping. —The size of the suctions to the house pumps and circulating pumps is calculated for a velocity of from 300 to 400 feet per minute, and usually given by the manufacturers. Where long suction pipes are required and priming, therefore, is inconvenient, it is necessary to use foot-valve. These foot-valves should be provided with a screen to guard against foreign material. Care should be exercised to have the pipes as tight as possible, in order not to destroy the suction. The pipes may be either of cast iron, wrought iron or steel. Either screwed or flanged pipes may be used, according to size and opinion.

Vacuum and Hot Well Piping. — The vacuum pipe should have as few sharp bends as possible; long sweep bends of either cast iron or steel should be used. It is

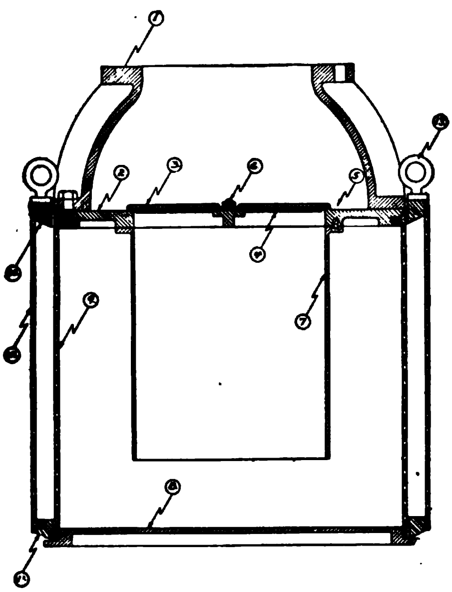


FIG. 6. Newman Foot-Valve provided with Section Pipe Extension and Double Screens.

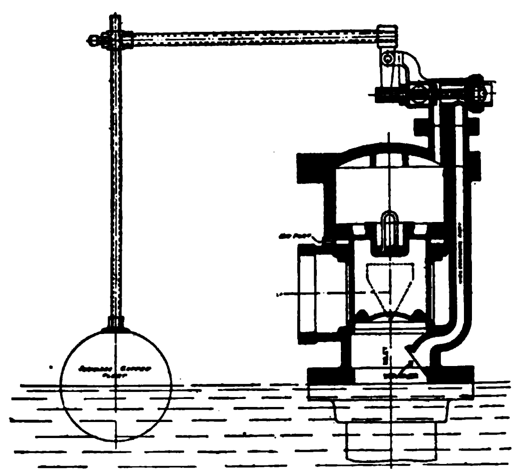


FIG. 7. Anderson Float Valve.

of vital importance that all joints be perfectly tight, or else a vacuum cannot be maintained. The discharge end of the pump may be connected to the main exhaust riser outside of the back-pressure valve.

Where the discharge of more than one hot well pump is connected to one main hot well pipe leading to the heater, each separate discharge should be provided with a cut-off valve and check to prevent, in case a pump is shut down, the water of another backing into it.

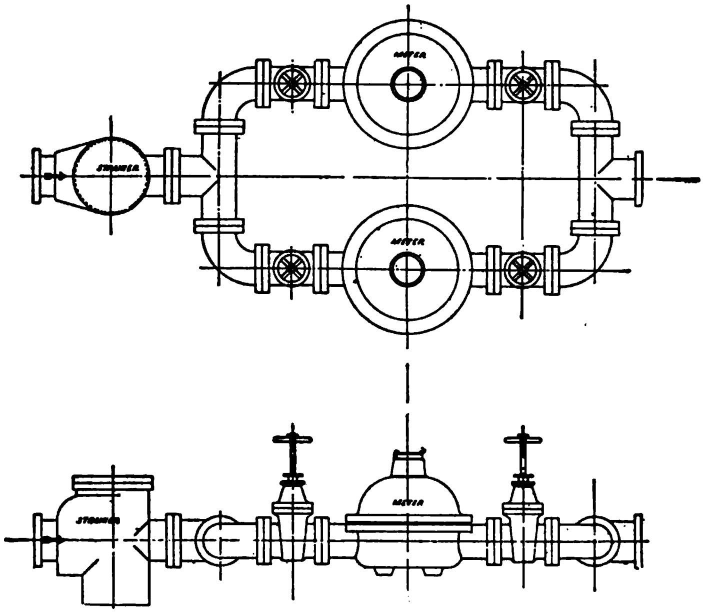


FIG. 8. Pipe Connection of Water Meter.

Covering. — All piping, such as auxiliary exhaust to heater, return of drips and the boiler feed suction, as well as the heater itself, should be covered with insulating material, similar to high-pressure covering, but may be of lower grade or of less thickness.

CHAPTER VI.

PRIME MOVERS.

Comparison of Engine and Turbine. — Prime movers may be classified as reciprocating engines and turbines. The choice of either of these types for the station is a matter of opinion; the reciprocating engine is the older of the two and is entirely out of the experimental class, whereas the larger number of turbines have not, as yet, been thoroughly developed. Some of the many advantages claimed for the turbine, namely, less steam consumption per unit capacity, ability to withstand continuous operation without shut-down, and ability to use high temperature superheated steam are, in many instances, overrated. These possible advantages are more or less offset by the more positive knowledge possessed by the manufacturers of the action and steam consumption of the reciprocating engine.

As to the steam consumption of the two types there is considerable variation, but this variation is due to the difference in manufacture rather than the difference in type. For instance, the average steam consumption of first-class Continental prime movers, both reciprocating engines and turbines, is from 11 to 9 pounds per I.H.P. hour, while English and American prime movers have a steam consumption of 13 to 11 pounds per I.H.P. hour. Of course, in both cases there are exceptions where lower steam consumption than the above given is obtained.

The above figures represent average everyday operation of first-class plants of their respective countries. The difference in the steam consumption between the American and English prime movers and those of the Continental type is due to the more careful manufacture of the latter. The high requirements specified by the power plant designer are undoubtedly the cause for this particular care in manufacture. It is the author's opinion that aside from any manufacture, it is within the reach of the power plant designer to greatly reduce the steam consumption, since the general layout of the plant as regards the relative location of boilers, engines, condensers, etc., and the connections between same, is of vital importance. In producing the most economical arrangement the designer shows his versatility and capabilities. After the plant has been erected its continued economical operation rests with the management. The plant designer should be careful to specify prime movers of low steam consumption, as it is unquestionably true that such machines are also of better manufacture and as durable as any other type.

In selecting a prime mover, of whatever type, one should be decided upon that is capable of withstanding a high degree of superheat; a prime mover cannot be classi-

fied as a modern or up-to-date engine that does not conform to this condition. By high degree of superheat, a temperature of from 600° Fahr. to 700° Fahr. is generally understood in Continental practice. It is claimed by certain American manufacturers that turbines cannot be economically operated with more than 100° to 150° Fahr. of superheat [about 475° to 525° Fahr. total heat (depending on pressure)]. This claim is hardly correct for good design and workmanship.

As already pointed out, some makes of turbines, which have been in the field long

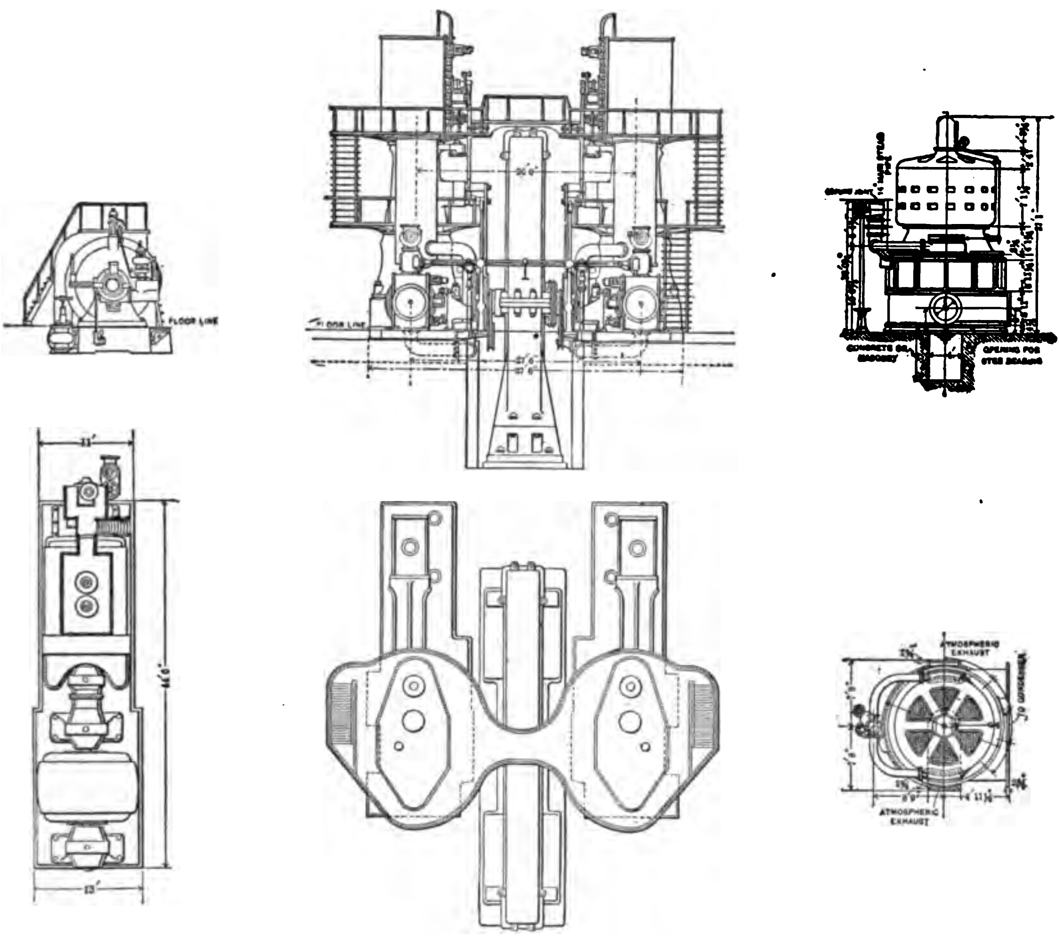


FIG. 1. Comparison of Turbines and Reciprocating Engines (*Power*).

enough to be of better construction, still daily show defects and give trouble. There have been turbines installed within the last few years which, even with a low temperature of superheated steam (100° of superheat), would cease to run. The expansion of the turbine chamber is so unequal and the clearance between moving and stationary buckets is minimized to such an extent that the working of the turbine will be stopped or the parts entirely destroyed. In the latter case new buckets must be installed.

It certainly would not be in the line of economy to ship with each turbine thousands of extra buckets to replace those which must be ripped out, to say nothing of the cost of replacing them and the delay in operation. Some manufacturers have endeavored, and with excellent results, to correct these evils by proper distribution of the metal of the turbine chamber, by allowing more clearance and by reinforcing the buckets.

In consequence of similar trouble occurring in some turbines or in consequence of other trouble in connection with the superheater, the use of superheated steam has sometimes been abandoned and saturated steam supplied. In order to facilitate the use of saturated steam in such cases, an adjustable arrangement has already been supplied in the design of the turbine, so that the clearance between the stationary and moving parts may be regulated to accommodate the use of saturated steam. This is a troublesome procedure, and it is understood that at present other remedies are being provided to overcome the troubles.

An advantage possessed by the turbine over the reciprocating engine is that it uses considerably less oil, since there are fewer and smaller bearings. However, a large amount of oil must be circulated through the bearings properly to flush same. Another very important factor in favor of the steam turbine is that the water of condensation from the surface condensers may be immediately sent to the boilers; with the reciprocating engine the water of condensation must first have the cylinder oil extracted. Another advantage is that the turbine requires a lighter foundation, as it is practically free from vibration and may, if necessary, be mounted on a floor above the boiler room.

Fig. 1 shows plan and elevation of vertical engine and turbines drawn to the same scale for the purpose of comparison, and represents 5,000 K.W. units. The center illustration shows a Reynolds horizontal, vertical, four-cylinder, compound engine. On the right hand a Curtis turbine is shown and on the left hand a Parsons. It would, however, be unfair to compare prime movers only, as the turbine is usually equipped with much larger condensers and auxiliary machinery.

In considering, therefore, a comparison between the floor space occupied by a turbine and a reciprocating engine, the actual space occupied by the prime movers, condensers and auxiliaries should alone be considered. The space occupied by the switch-board should not figure in the comparison. The following figures show such a comparison between a few of the recent plants:

Plant.	Square Feet per K.W.	Type.
Bow Road Station, London	0.908	Horizontal and Vertical Engines
Fifty-ninth St., New York	1.085	Vertical Engines
Chelsea, London	0.413	Horizontal Turbines
Potomac, Washington	0.388	Vertical Turbines
Delaware and Hudson Co., Mechanicville, N.Y.	0.561	Vertical Turbines

Size of Prime Movers. — The size of prime movers depends upon the capacity of the plant and also on the load factor. In selecting, care should be taken that a unit

or two (depending on size of plant) should be kept in reserve. The practice is to install as large prime movers as possible. There are to-day 9,000 K.W. units (normal capacity) in operation, and it will probably not be long before 12,000 K.W. units will be introduced. The size of prime movers and especially of the turbine, within reason, is not limited; it must, however, be remembered that the larger the unit the greater the inconvenience in case of a break-down.

Power plants for railroading as well as for lighting are subject to great fluctuation in load, therefore reserve units are of special importance. In order to reduce to the greatest possible extent the number of reserve units, American designers have introduced prime movers capable of withstanding 50 per cent overload. This practice has to a certain extent been adopted in Great Britain, but not on the Continent of Europe, where the overload capacity amounts to 20 to 30 per cent. It is the author's opinion that a prime mover designed for 50 per cent overload is in reality rated below its actual normal output. The rated horse-power of a prime mover should be that at which it operates most economically; it is therefore loss in economy to underrate a prime mover, provided it operates at full rated load. Practice shows that these prime movers capable of 50 per cent overload operate most economically at about 20 per cent overload.

The method of obtaining overload from a reciprocating engine is to retard the cut-off, while with turbines a secondary valve admits high-pressure steam to a later point in the expansion rings of the turbine.

RECIPROCATING ENGINES.

Classification.—There are numerous forms and designs of reciprocating engines. If sufficient floor space is available, horizontal engines may be adopted; if, however, the floor space is limited, those of the vertical type may be used. Engines are built with either one, two, three or four cylinders and are called simple, compound, triple expansion or quadruple expansion, respectively.

Engines are built either right or left hand — they are classified differently by various manufacturers. The majority, however, classify them as shown in Fig. 2. Referring to this diagram, an engine is "right hand" if the cylinder is on the right hand looking towards the fly wheel from the rear of the engine, and *vice versa.* Taking the same position, if the uppermost position of the fly wheel moves away from the observer the engine is said to run "forward" or "over," while if it turns towards the observer the engine runs "backwards" or "under." If the engine is cross compound, the high-pressure cylinder is alone taken into consideration when classifying as to right or left hand. These classifications apply to both horizontal and vertical engines.

Engines are also classified as low and high speed. The low-speed engines are those used for the main generator units and have a speed of from 70 to 150 R.P.M. according to size. High-speed engines are practically exclusively used for driving exciters, circulating pumps, fans, etc., and they run at from 150 to 400 R.P.M.

Modern practice is to direct-connect the generators to the engines, thus doing away with all gearing or belting; the resultant saving in friction is considerable and at the same time the floor space is reduced.

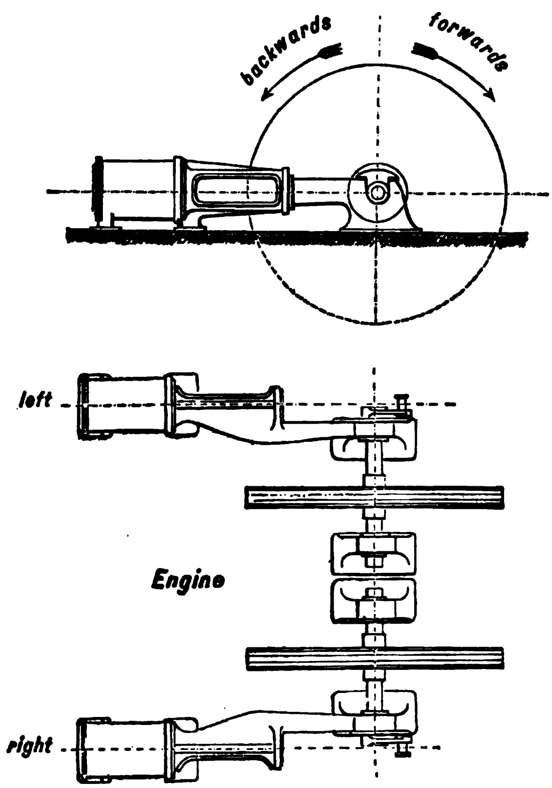


FIG. 2. Right and Left Hand Engine.

Valve Mechanism. — One of the most important features in the successful operation of a reciprocating engine is the valve gearing. The power plant designer in selecting an engine should consider well the type of valve gearing and governing device best adapted to the plant's particular needs and requirements. Whichever type is selected, be it Corliss, piston or gridiron, etc., it should be able to withstand highly superheated steam. Within recent years many contributors to the technical press have claimed that a Corliss valve would not operate with superheated steam so successfully as a poppet valve. This claim in the author's estimation is ungrounded, as it is based principally on European engines, equipped with poppet valves and using highly superheated steam, and showing a remarkably low steam consumption. There are, however, numerous examples of Corliss and similar valves operating under the same conditions with equally good results. Low steam consumption is more a matter of workmanship and the design of the entire engine, than a question of valve mechanism.

It is true that superheated steam, being rarer than saturated steam, will escape more readily and therefore will require a closer fitting valve. When the plant designer is looking toward economical operation, as he always should do, he will select machines which are the best of their respective kinds and class.

In order to throw an engine in parallel with other engines already running, it is necessary to synchronize the particular generator with the others. This is done in well-designed plants from the main switchboard. A small motor controlled from the switchboard is directly connected with the governor, which enables the operator to control the engine speed to any desired point.

Simple Engines. — The simple engine works with limited expansion; its first cost is low, but the steam consumption is high. One of the best engine manufacturers gives

the steam consumption of a simple engine at from 22 to 27½ pounds per I.H.P. hour, assuming a working steam pressure of from 70 to 140 pounds. When superheated steam is employed of a total temperature of from 400° to 650° Fahr. the consumption will be reduced from 2.25 to 5 pounds. These engines are mostly used for small and variable loads and are frequently non-condensing. By running these engines condensing the consumption will be reduced ¼ to ⅓ below that of a non-condensing engine.

If two simple engines are connected to the same shaft, they are called twin engines. In this case the crank shafts are usually placed at an angle of 90° from each other, thus giving a more uniform impulse. Should a single cylinder engine be installed and the future load not be known, a second cylinder may very conveniently be added in this manner. A more economical method of accomplishing the same result would be to compound the engine by the installation of a low-pressure cylinder.

Fig. 3 shows a simple engine of the Allis-Chalmers type, direct-connected to a generator. It will be noticed that the engine is provided with Corliss valve gearing operated

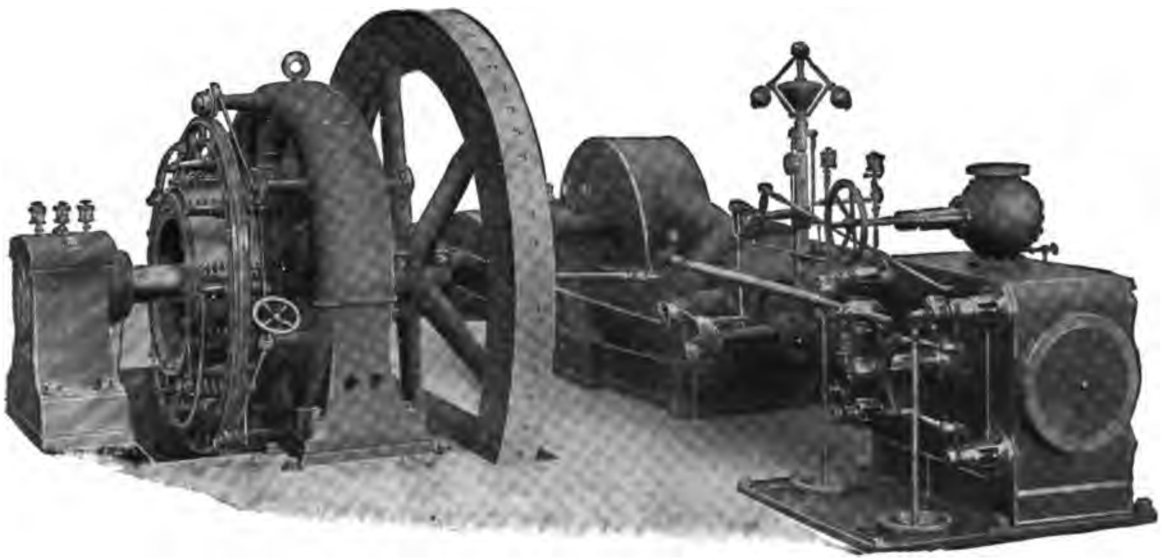


FIG. 3. Direct-Connected Single Cylinder Corliss Engine.

by an eccentric on the shaft, the motion being transmitted to the wrist plate by a rocker arm. The governor is of the usual fly-ball type, belted to the main shaft and regulating the cut-off automatically as required. These engines are manufactured of practically any desired size and for service as above mentioned, they may operate either condensing or non-condensing. Their first cost is low, while the operating cost naturally is high.

Compound Engines.— Where the load is heavy and to secure a greater economy of steam consumption, a compound engine may be installed. These engines are either cross compound or tandem compound. In the former the cylinders are side by side;

in the latter, one behind the other with the pistons on the same piston rod. The compound engine may be supplied with a receiver into which the exhaust from the high-pressure cylinder is discharged, and from which the steam to the low-pressure cylinder is taken. Sometimes these receivers are supplied with a steam coil, through which boiler-pressure steam is circulated, for the purpose of reheating the steam and prevent-

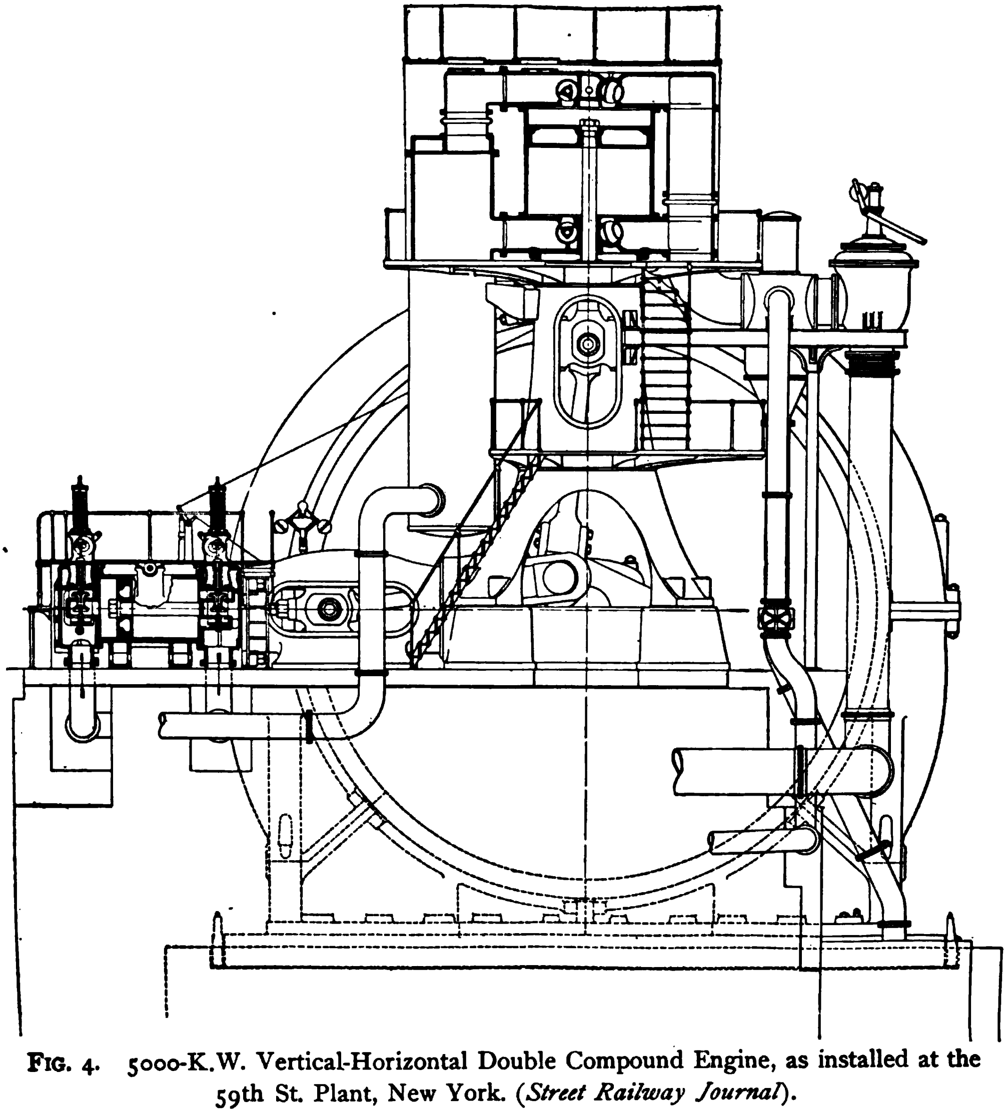


FIG. 4. 5000-K.W. Vertical-Horizontal Double Compound Engine, as installed at the 59th St. Plant, New York. (*Street Railway Journal*).

ing condensation. Where there are no reheating coils installed, it is good practice to steam jacket the low pressure cylinder, for the same reason as given above. It does not pay to provide the high-pressure cylinders with a steam jacket.

If tandem compound engines are used a wider engine room is required, while where cross compound engines are used a longer engine room is necessary. There is less

friction in a tandem compound engine than in a cross compound, but it requires a heavier fly wheel. The steam consumption of both types (of best manufacture) amounts to about 16.5 to 13 pounds per I.H.P. hour for saturated steam at from 90 to 175 pounds pressure; with the use of superheated steam from 500° to 650° Fahr., these figures are reduced by 1 to 3.5 pounds.

Compound engines are built either of the vertical or horizontal type or a combination of both. In the latter case one crank pin only is necessary — sometimes there are two such sets connected to the same shaft, with the generator mounted between; these engines are called double compound vertical-horizontal engines. Fig. 4 illustrates a type of this class, known as the "Manhattan" and installed both at the 79th Street and 59th Street power houses in New York. They are manufactured by the Allis-Chalmers Company.

The principal dimensions of the 59th Street station engine (Fig. 4) are as follows:

High-pressure cylinders	42″
Low-pressure cylinders	86″
Stroke	60″
Revolutions per minute	75
Pressure	175 lb.

The high-pressure cylinders, which are of the horizontal type, are provided with poppet valves, the low-pressure cylinders are provided with Corliss valves. The poppet valves are regulated in a similar manner to the Corliss valve, that is, by an eccentric and a wrist plate. Such valve combination is a very unusual practice. This engine is rated at 7,500 horse-power and capable of 50 per cent overload. The best steam consumption was had at 8,000 horse-power and was 11.9 pounds per I.H.P. hour.

Triple Expansion Engines. — These engines are not used to any great extent in stationary work in America, but have been broadly adopted in Europe, because of their lower steam consumption. This consumption is usually guaranteed by first-class manufacturers to be from 12 to 11 pounds for saturated steam; where superheated steam is used from 400° to 700° Fahr., the consumption will be reduced from ½ to 2½ pounds.

These engines are frequently built with four cylinders having one high-pressure and one intermediate cylinder, and two low-pressure cylinders. Their chief disadvantage is their increase in first cost. A notable example of a four-cylinder, triple expansion engine, as installed at the "Moabit" plant in Berlin and as manufactured by Sulzer Bros., is shown in Fig. 5.

This engine * is 6,500 I.H.P. and its dimensions are as follows:

High-pressure cylinder	51¼″
Intermediate-pressure cylinder	60⅛″
Low-pressure cylinder	72⅞″
Stroke	66⅞″
Revolutions per minute	83

* From the author's article in the *Engineering Record*, May 12, 1906: "The Equipment of Two Berlin Power Plants."

This engine, operating at a pressure of 12 atmospheres (176.4 pounds) and a steam temperature of 572° Fahr., develops as follows:

15 per cent cut-off	3450 I.H.P.	3000 B.H.P.
23 per cent cut-off	4470 I.H.P.	4000 B.H.P.
32 per cent cut-off	5490 I.H.P.	5000 B.H.P.
50 per cent cut-off	6500 I.H.P.	6000 B.H.P.

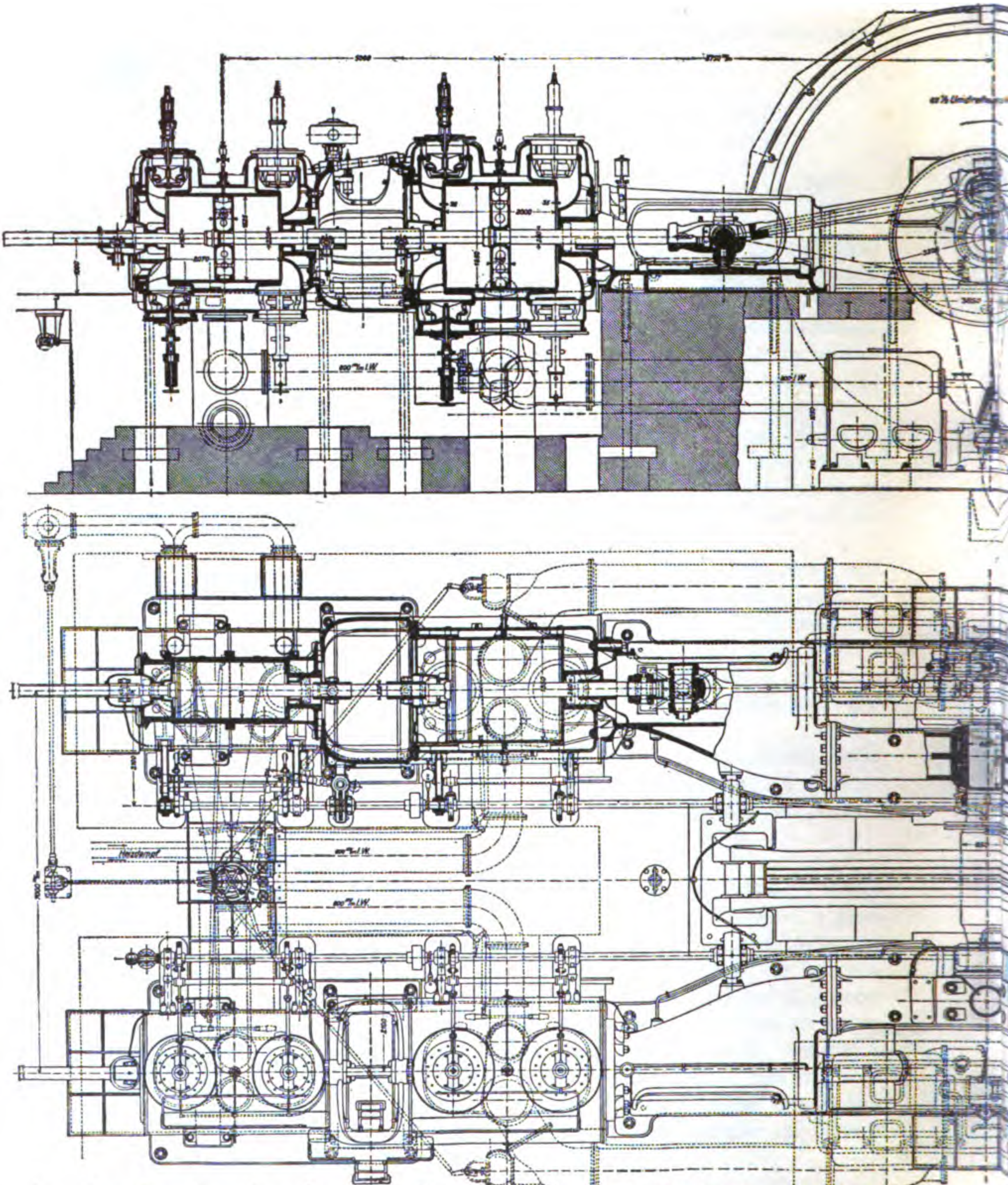
The high- and intermediate-pressure cylinders are furthest from the generator, thus facilitating the steam connection and avoiding as much as possible highly heated parts close to the generator. Therefore the two low-pressure cylinders are bolted directly against the frame of the crosshead guides. Between the high- and low-pressure cylinders are distance pieces, with openings at the top to allow access to the stuffing boxes. Heavy distance bolts are provided between the cylinders as shown in the illustration to reinforce the frame. Except the high-pressure cylinder, all cylinders, including the heads, are steam jacketed and supplied with steam at 75 pounds pressure. Each cylinder possesses 4 four-seated poppet valves, two valves are at the bottom and two at the top; access to the former is from the basement. All valves are operated from the main shaft by means of worm gearing. The governor is of the Hartung type.

The hollow engine shaft is supported on bearings 22½ inches in diameter and 45½ inches long, the central portion of the shaft supporting the generator being increased to 33½ inches. On account of the weight of the revolving part of the generator, the bearings are water cooled. This same water also serves to cool the lower parts of the crosshead guides. From each crank is operated a double-acting air pump, located in the basement, as will be seen in the illustration. All stuffing boxes are provided with United States Metallic Packing.

Tests made on this engine show under actual operating conditions and under normal full load, and with a pressure of from 177 pounds to 188 pounds at a temperature of 572° Fahr., an average steam consumption of 4.03 kilograms (8.806 pounds) per indicated horse-power hour.

Quadruple Expansion Engines. — Quadruple expansion engines, although largely used in marine work, are seldom employed in stationary work. However, a noteworthy example of this type was exhibited at the World's Fair in St. Louis by the Société Anonyme des Etablissements Delaunay Belleville, St. Denis. It is a six-cylinder, vertical type of 1,500 horse-power capacity and direct connected to a 1,000-K.W. generator; the generator is connected on one end of the shaft, while the condenser, pumps, air and circulating, are connected to the opposite end of the shaft. See Fig. 6.

This engine has one high-pressure cylinder located in the center, two first intermediate cylinders located on both sides of the former one, a second intermediate cylinder located in the center, directly below the high-pressure cylinder and between the two low-pressure cylinders.



Heizdampf

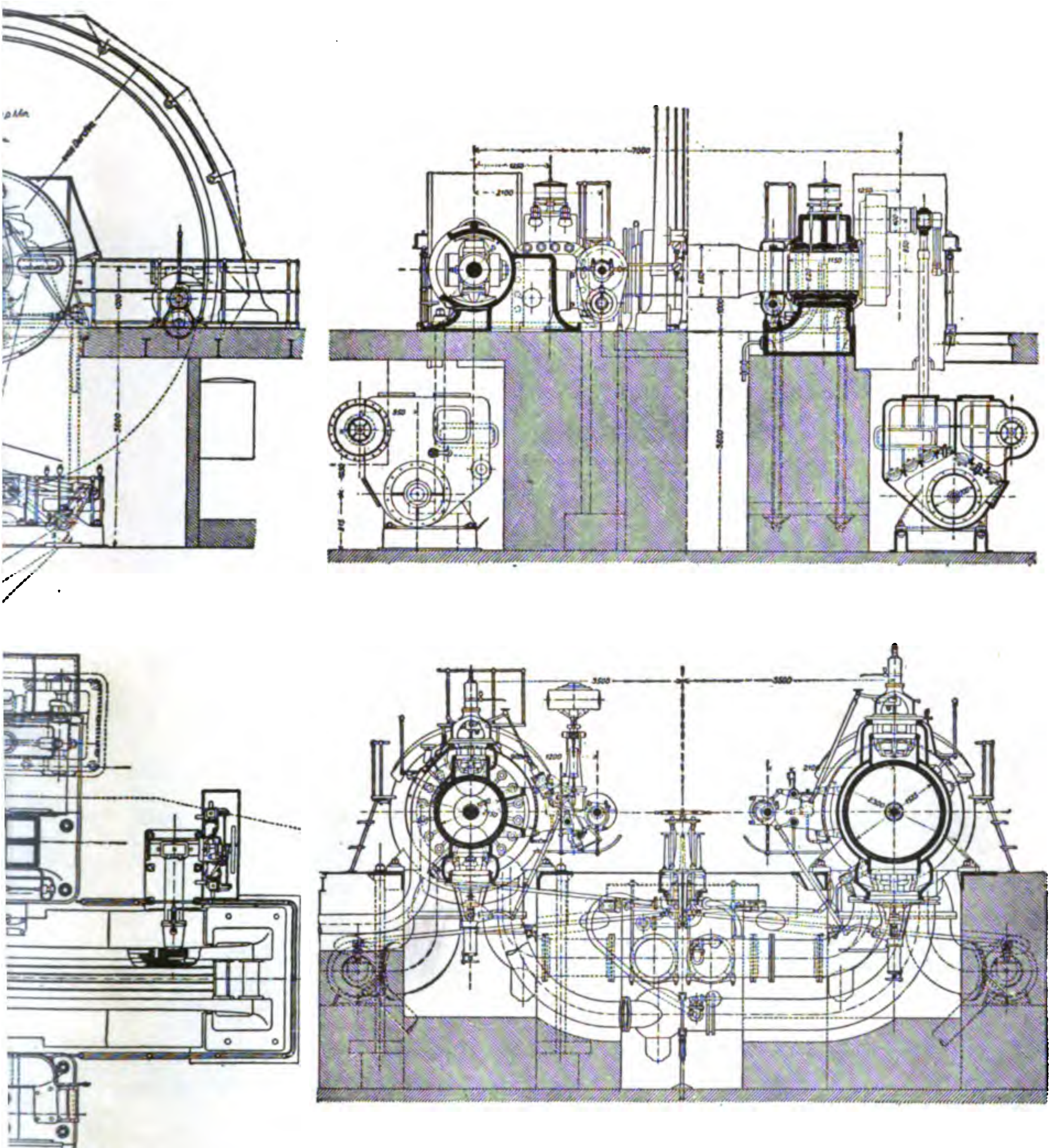


FIG. 5. Sulzer, Four Cylinder, Triple Expansion, Superheated Steam Engine (4700 K.W.) as installed at the Moabit Plant, Berlin, operating at Normal Full Load with a Steam Consumption of 9.1 lbs. per I.H.P. hour.

The dimensions of this engine are as follows:

High-pressure cylinder	$13\frac{3}{8}''$
First intermediate-pressure cylinder	$13\frac{3}{8}''$
Second intermediate-pressure cylinder	$26\frac{3}{4}''$
Low-pressure cylinder	$26\frac{3}{4}''$
Stroke	$17\frac{1}{4}''$

This engine is designed for an initial pressure of 300 pounds and a total steam temperature of 750° Fahr. It will be noticed that none of the cylinders are jacketed.

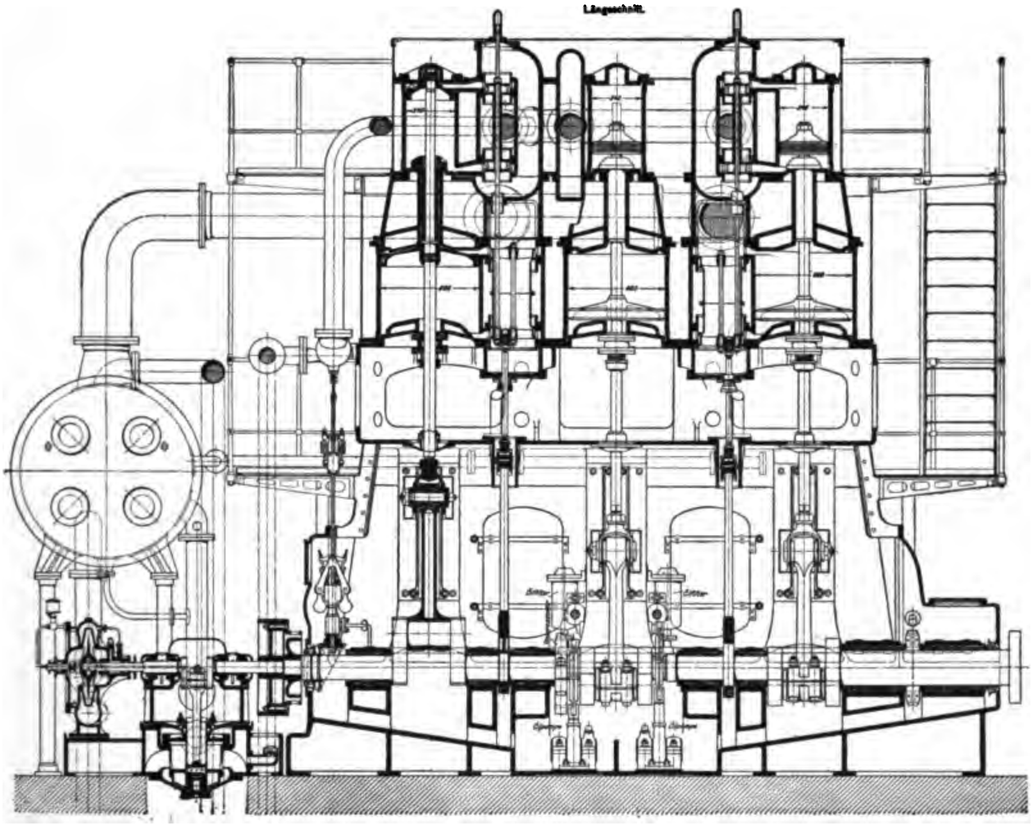


FIG. 6. Six Cylinder, Quadruple Expansion, High Speed Engine (1000 K.W.).

The valves are of the piston type. Although this engine may not be adaptable to general power plant practice, it is an interesting example of its class.

TURBINES.

Classification. — Steam turbines may be classified as impulse and reaction. The former may be sub-classified as single impulse and compound impulse. In the impulse type the steam expands either in a nozzle or in the stationary vanes, or both. In the reaction type the steam expands in the rotating vanes.

The single impulse type is represented by the De Laval turbine, the multiple impulse types are turbines such as the Curtis, Rateau, Zoelly, etc. The Parsons turbine, as manufactured by various concerns, is the only one of the reaction type. There are also turbines of the combined impulse and reaction type, such as the Terry and Sulzer.

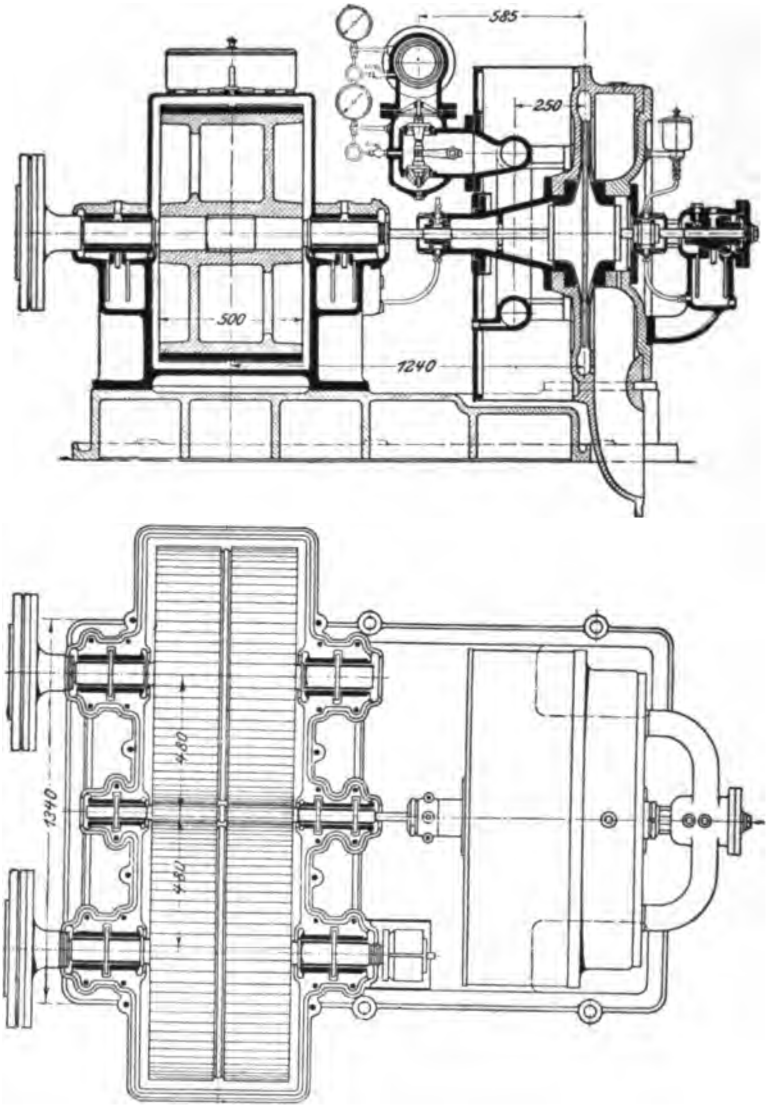


Fig. 7. De Laval Turbine.

Single Impulse Turbines. — The single impulse turbine (De Laval), which may also be classified as single stage type, is shown in Fig. 7. It consists of a single wheel, mounted on a flexible shaft; has an extremely high velocity, amounting

with a 5-K.W. turbine to 30,000 R.P.M., while with a 200-K.W. turbine the velocity is as high as 10,000 R.P.M. This type of turbine is rarely built larger than 200 K.W. capacity. The high velocity of these turbines requires that when using them for commercial purposes gearing has to be employed. These gears are made of solid cast steel or iron. When connected to generators, there are usually two generators in a set rotating in opposite directions. In power-house work these turbines may be employed for blowers, centrifugal pumps, etc.

The action of the turbine is as follows:

The steam, after passing the throttle, enters a number of expansion nozzles in which the steam is completely expanded in passing to the buckets, thus transferring the kinetic energy to the turbine wheel, from which it passes to the exhaust opening.

Compound Impulse Turbines.—The compound impulse turbine consists of two or more stages, the steam passing successively from one to the other, finally discharging through the exhaust port. The Curtis turbine, which is the most successful in use in America, is built on this principle. The earlier styles were of the two-stage type, while in the present design four stages are employed.

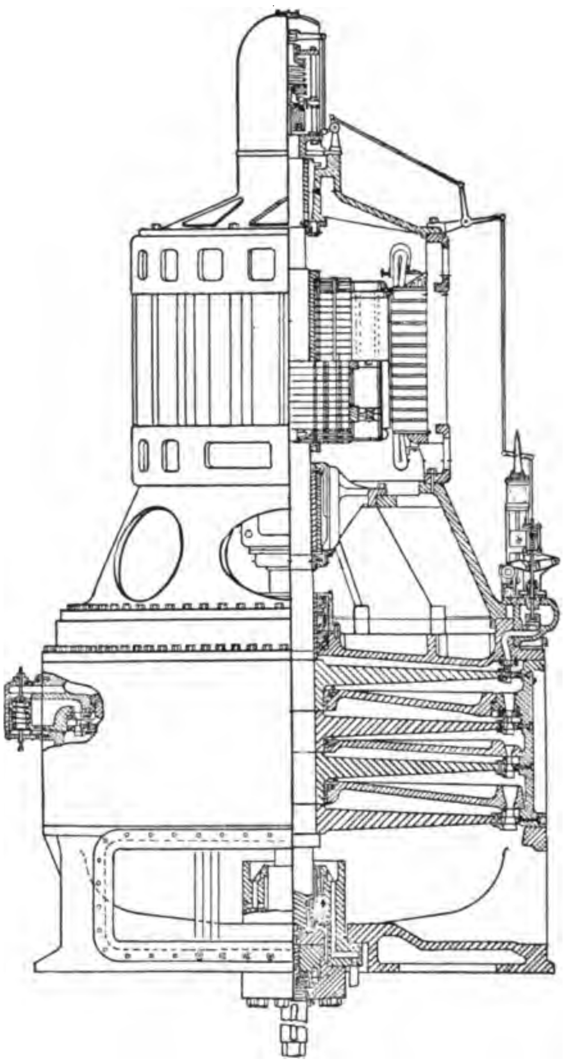


FIG. 8. Half Cross-Section of Curtis Turbine and Generator.

This Curtis turbine is built both vertical and horizontal. The former are practically exclusively used for the main generator units, while the latter are built of smaller capacity and may be used for exciters. As will be seen in Fig. 8, which shows a four-stage vertical Curtis turbine, the generator is mounted on top of the turbine directly connected to the shaft, the latter resting in an adjustable step bearing. Oil is supplied to the step bearing by high-pressure pumps, so that when the turbine is in operation

the shaft revolves upon a film of oil. Provision is made so that a continuous flow of oil will always be preserved, either by means of duplicate pumps or else by the use of an accumulator, as will be seen in an article on oiling system.

Steam is admitted to the first stage through a number of pilot valves automatically controlled by a single governing device, from which it passes successively to the buckets of the wheels, expanding in same, and passing the diaphragms, which are placed between the rotating wheels. Unlike many other turbines, the buckets are not riveted or caulked to the wheel, but are milled out of solid discs, thus entirely eliminating the possibility of rupture in this part of the turbine. A great number of these turbines have been installed in the more prominent plants in America, the largest types of which, at present, are of 9,000 K.W. normal capacity. Turbines of this size are installed in the Fisk Street station of the Commonwealth Electric Power Company of Chicago, Ill., where also four 5,000-K.W. units are installed.

A series of tests were made on one of these 5,000 K.W. units, a report of which is as follows:

All the tests, except the speed tests, were made under regular commercial load conditions. On account of the change in frequency in the speed tests the load was

TABLE I.

Load Kw.	Steam Pressure (Gauge)	Superheat °F	Gross Flow, Pounds Per Hour	Condenser Leakage, Pounds Per Hour	Back Pressure Inches Mercury	R. P. M.	Water Rate—Lbs. Per Kw. Hr. Actual	Water Rate—Lbs. Per Kw. Hr. Reduced to 150° Superheat, 1½ in. Back Pressure, 175 lbs. Steam Pressure.	Notes
3340	171	151	56690	1070	89	500	16.66	17.29	Water Rheostat
5940	169	180	98370	950	1.72	"	16.40	16 55	Commercial
2920	172	158	50930	1050	1.08	"	17.08	17.61	Commercial
4860	179	180	81550	1700	1.55	"	16.50	16.81	Water Rheostat
7525	175	147	130200	820	2.09	"	17.19	16.91	Water Rheostat
4950	180	171	80570	220	1.48	"	16.23	16.55	Commercial
0	178	150	3520	220	1.40	"	....	......	Full Voltage

TABLE II.

Load Kw.	Steam Pressure (Gauge)	Superheat °F	Gross Flow, Pounds Per Hour.	Condenser Leakage, Pounds Per Hour	Back Pressure Inches Mercury	R. P. M.	Water Rate—Lbs. Per Kw. Hr. Actual	Water Rate—Lbs. Per Kw. Hr. Reduced to 150° Superheat, 1½ in. Back Pressure, 175 lbs. Steam Pressure. 640 R. P. M.	Notes
*3530	170	165	55900	1070	.85	650	15.55	16.40	Water Rheostat
5140	180	179	81930	1700	1.50	640	15.67	16.03	Water Rheostat
8090	177	141	131160	820	2.03	640	16 11	15.80	Water Rheostat

* Average of two points.

Test of 5000-K.W. Curtis Turbine at Fisk St. Plant, Chicago.

absorbed by plates in the Chicago River. It was found that for a given load the commercial load water rate was identical with that obtained by the use of a water rheostat, other conditions remaining the same.

In the commercial tests a constant load was maintained on the turbine under test by varying the tension of the auxiliary governor spring, controlled by a motor at the switchboard. Steam pressure and superheat were kept as nearly constant as possible by proper attention at the boilers.

All tests were made at about 150° superheat. The temperature was read by calibrated mercury thermometers placed in wells filled with mercury and correction was made for the exposed stem. The temperature and pressures were read every five minutes.

The amount of steam was obtained by discharging the condensed steam into tanks where it was weighed. After each run the condenser was tested for leaks, which, as shown by the tables, were of small amount.

The result of the tests are shown in Tables I, II, III and IV. To make the tests comparable, all results were reduced to 150° superheat, 1½ inches back pressure, and 175 pounds (gauge) steam pressure. The actual and the reduced water rates are given in the table:

TABLE III.

SUMMARY OF TABLE I.

500 R.P.M.
150 Degrees Superheat.
1½ Inches Back Pressure.
175 lbs. Steam Pressure (gauge).

Load.	Water Rate.
2500 K.W. (½ Load)	17.74
3750 " (¾ ")	17.08
5000 " (Full ")	16.62
6250 " (1¼ ")	16.52
7500 " (1½ ")	16.90

TABLE IV.

SUMMARY OF TABLE II.

650 R.P.M.
150 Degrees Superheat.
1½ Inches Back Pressure.
175 lbs. Steam Pressure (gauge).

Load.	Water Rate.
3750 K.W. (¾ Load)	16.35
5000 " (Full ")	16.07
6250 " (1¼ ")	15.88
7500 " (1½ ")	15.80

The Rateau turbine, similar to the Curtis, is also of the compound impulse type; as this turbine consists of a large number of wheels, it is frequently called multiple impulse. The sectional view, Fig. 9, represents this turbine as manufactured by Sautter, Harle & Co., Paris. This particular design is arranged in two separate cylinders, thus enabling a bearing to be placed between the two. Frequently, however, the entire rotating part is enclosed in a single cylinder.

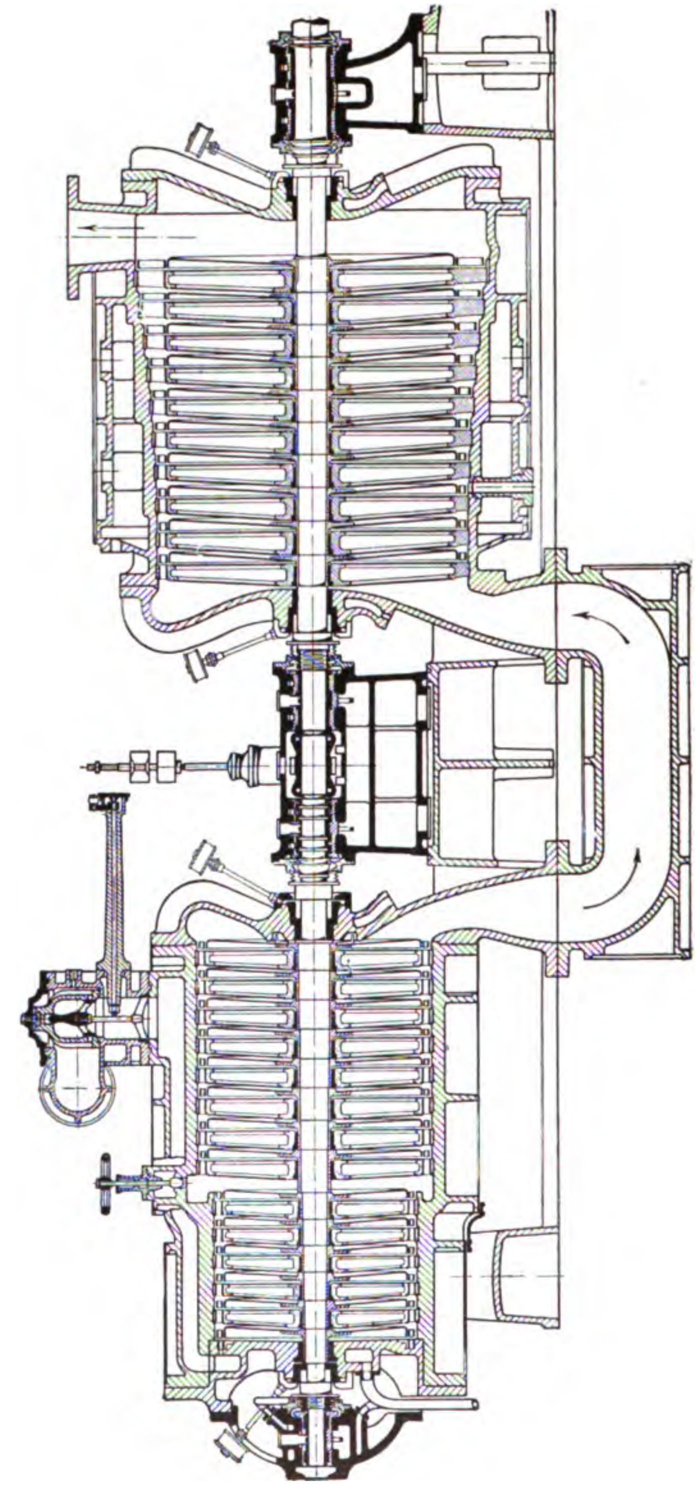


FIG. 9. Rateau Turbine with Separate Cylinders as Manufactured by Sautter, Harlé and Co., Paris.

Size of Turbine																				
Vacuum in Exhaust	26 Inches.										27									
Throttle Pressure Lbs. Gauge	135			140				150												
Condition of the Steam	Dry and Saturated.			Quality = 99%.				Dry and Saturated.			Dry and Saturated.								5°	
Revolutions per Minute	3,600			3,600				3,600			3,600									
Turbine Number	28			35				51			47			49			55			
1 Steam pressure lbs. per gauge	135.6	134.9	130.6	142.8	144.0	144.5	138.2	151.6	151.4	149.8	153.4	153.2	153.1	152	156	155	*152	*155	140.9	148.
2 Vacuum referred to 30-inch barometer	26.0	26.02	26.03	26.0	26.0	26.0	26.0	26.06	26.06	26.06	27.04	27.11	27.06	27.15	27.2	27.25	27.01	27.01	27.0	27.
3 Superheat, degrees Fahrenheit	2.5	.....	.....	.....	.....	.....	.....	.....	2.0	4.0	.....	.....	.....	3.0	5.0	.....	.....	.....	7.0	5.
4 Quality of the steam	.....	.999	.999	.989	.989	.99	.948	1.00	.....	.....	1.00	1.00	.998	.....	.....	.997	1.00	1.00	.....	
5 Revolutions per minute	3,536	3,555	3,545	3,511	3,557	3,582	3,589	3,541	3,599	3,598	3,528	3,576	3,563	3,520	3,565	3,577	3,497	3,549	3,541	3,56
6 Load in kilo-watts	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	438.1	298.4	211.6	.....	.....	.....	.....	.....	.....	
7 Load in electrical horse-power	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	587.3	400.0	283.6	.....	.....	.....	.....	.....	.....	
8 Load in brake horse-power	580.1	457.2	326.0	623.4	508.2	381.0	10.7	610.8	451.4	266.1	.....	.....	.....	651	435	261	691	593.5	607.7	441.
9 Total pounds of steam per hour	8,940	7,481	5,834	9,502	7,992	6,311	1,085	8,917	6,916	4,542	8,739	6,205	4,774	9,200	6,472	4,411	9,734	8,514	8,882	6,62
10 Pounds of steam per E. H. P. hour	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.89	15.51	16.81	.....	.....	.....	.....	.....	.....	
11 Pounds of steam per B. H. P. hour	15.41	16.36	17.89	15.24	15.73	16.56	.....	14.59	15.32	17.06	.....	.....	.....	14.15	14.88	16.9	14.1	14.35	14.61	15.0
12 Load in per cent. of full load	98	77	55	105	86	64	2	108	77	45	109	75	53	110	74	44	119	100	103	75
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Size of Turbine	400 K. W.												1,000 K. W.					
Vacuum in Exhaust	28 Inches.												27 Inches.				25 Inch	
Throttle Pressure Lbs. Gauge	150												130				150	
Condition of the Steam	100° Superheat.				150° Superheat.			180° Superh.		190° Superheat.			Quality = 100%.				Quality =	
Revolutions per Minute	3,600				3,600			3,600		3,600			1,500				1,500	
Turbine Number	55				54			55		67			15				17	
1 Steam pressure lbs. per gauge	*150	*150.3	*154.5	*153.8	150.6	149.4	150.2	*150.2	*153.6	148.4	147.9	149.1	133.5	133.7	134.3	139	148.7	150.5
2 Vacuum referred to 30-inch barometer	28.01	28.01	28.01	28.01	28.0	28.0	28.0	28.08	28.1	28.0	28.0	28.0	27.02	27.0	27.06	26.83	25.07	25.0
3 Superheat, degrees Fahrenheit	104	104	106	86	139	156.8	150	182	180	192	185	157	.....	.....	.....	.....	.....	.....
4 Quality of the steam	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.999	.999	.999	.998	.98	.9
5 Revolutions per minute	3,456	3,544	3,561	3,627	3,538	3,586	3,595	3,478	3,543	3,551	3,571	3,583	1,489	1,498	1,508	1,518	1,496	1,50
6 Load in kilo-watts	.....	.....	.....	.....	.....	.....	.....	.....	.....	428.4	303.8	197.8	1,101.7	786.7	530.7	380.1	1,506	91
7 Load in electrical horse-power	.....	.....	.....	.....	.....	.....	.....	.....	.....	571.5	407.2	265.1	1,476.8	1,054.5	711.4	509.4	2,015	1,22
8 Load in brake horse-power	759	593	445	264	626	451	296.8	763	592	.....	.....	.....	.....	.....	.....	.....	.....	.....
9 Total pounds of steam per hour	9,157	7,408	5,728	3,504	7,426	5,394	3,919	8,520	6,795	7,444	5,626	4,126	21,964	16,867	12,775	10,547	32,924	23,03
10 Pounds of steam per E. H. P. hour	.....	.....	.....	.....	.....	.....	.....	.....	.....	13.02	13.81	15.56	14.9	15.99	17.95	20.73	16.32	18.8
11 Pounds of steam per B. H. P. hour	12.06	12.5	12.87	14.48	11.86	11.87	13.2	11.17	11.46	.....	.....	.....	.....	.....	.....	.....	.....	.....
12 Load in per cent. of full load	128	100	75	45	106	76	50	129	100	106	76	50	110	79	53	38	120	73
	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61

Size of Turbine	1,250 K. W.															
Vacuum in Exhaust	28 Inches.			25 Inches.		26 Inches.		27 Inches.								
Throttle Pressure Lbs. Gauge	150			150		150		150								
Condition of Steam	140° Superheat.			Dry Saturated.		Dry Satur'd.		Dry Saturated.								
Revolutions per Minute	1,500			1,200		1,200		1,200							1,	
Turbine Number	17			43		43		41								
1 Steam pressure lbs. per gauge	154	149.5	148.9	146.4	143.4	147	148.9	‡141.8	‡144.5	‡148	‡147.1	‡146.5	‡146.8	‡151.4	‡150.3	146.3
2 Vacuum referred to 30-inch barometer	28.1	28.04	28.17	25.01	25.05	26.01	26.05	26.79	26.05	27.05	27.11	27.11	27.11	27.1	27.08	27
3 Superheat, degrees Fahrenheit	141	139	133	2	3	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	2
4 Quality of the steam	.....	.....	.....	.....	.....	.....	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.999	.....
5 Revolutions per minute	1,500	1,500	1,503	1,199	1,201	1,198	1,202	1,197.4	1,200	1,201	1,196	1,197	1,199	1,201	1,201	1,199
6 Load in kilo-watts	1,512	904	306	.....	.....	.....	.....	1,988.9	1,713.5	1,489.4	1,321.5	969.5	656	342.7	197	.....
7 Load in electrical horse-power	2,030	1,210	412	.....	.....	.....	.....	2,666	2,297.1	1,996.5	1,771.4	1,296.5	879.3	459.4	264	.....
8 Load in brake horse-power	.....	.....	.....	2,006.3	1,004.4	2,002.3	1,007	.....	.....	.....	.....	.....	.....	.....	.....	2,005.3
9 Total pounds of steam per hour	25,685	17,042	8,106	28,902	16,809	28,236	16,106	40,547	33,036	28,206	25,712	20,254	15,074	9,732	7,150	27,248
10 Pounds of steam per E. H. P. hour	12.66	14.1	19.68	.....	.....	.....	.....	15.21	14.38	14.13	14.52	15.27	17.14	21.18	27.08	.....
11 Pounds of steam per B. H. P. hour	.....	.....	.....	14.39	16.73	14.10	15.99	.....	.....	.....	.....	.....	.....	.....	.....	13.59
12 Load in per cent. of full load	121	72	24	110	55	110	55	159	137	119	106	79	53	28	16	110
	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101

* Test made by Mr. F. W. Dean of Dean & Main, Boston. † Tests made by a board of naval engineers. ‡ Te

400 K. W.																						
ches.									28 Inches.													
0									150													
perheat.			100° Superheat.						Dry Saturated.								45° Superheat.					
,600			3,600						3,600								3,600					
53			37			39			55					36			56					
154	153.5	154	149.8	160.6	152.8	155.2	147.5	155	*153.6	*154.5	*156	*155.8	*159	151.7	154.5	159	148.5	149.6	150.8	153.1	150.7	150
27	27.0	27	27.01	27.0	27.0	27.05	27.0	27	28.01	27.98	27.92	28.01	28.01	28.0	28.0	28	27.78	28.03	28.0	28.01	28.02	28.02
4	2.0	.....	100	108.5	95.6	97.6	104.2	108.1									45.0	44.0	42.0	45.0	41.0	45.0
		.998							1.00	.999	1.00	.996	.986	.998	.992	1.00						
3,564	3,583	3,608	3,492	3,570	3,606	3,482	3,509	3,590	3,480	3,545	3,563	3,608	3,662	3,593	3,570	3,591	3,414	3,436	3,478	3,511	3,536	3,540
....	....	....	....	....	....	411.2	311.7	219	....	....	....	....	....	408	292.2	198.7	....	....	....	....	....	....
						551.1	417.9	298.7						539	391.7	266.3						
8.9	152.6	9.2	650.3	481	254.4				729	593.2	448	241	5.3				1,088.2	894.6	755.9	681.5	494.6	256.1
,774	2,881	953.5	8,778	6,657	4,089.5	7,425	5,780	4,272	9,998	8,269	6,488	3,878	706	8,169	6,172	4,640	14,587	11,080	9,998	8,417	6,015	4,018
						13.47	13.88	14.54						15.15	15.75	17.42						
5.52	18.88	.....	13.5	13.84	15.67	....	....	....	13.62	13.91	14.48	16.06	.....	....	....	....	14.12	13.36	13.28	13.56	14.16	15.55
49	26	.....	110	83	43	108	78	55	123	100	76	41	1	100	73	50	174	140	120	105	73	44
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43

1,250 K. W.																							
	26 Inches.			27 Inches.											27.5 Inches.						28 Inches.		
	150			150											150						150		
%.	Quality = 98%.			Quality = 98%.			Quality = 99%.				50° Superheat.				Dry Steam.		25° Superheat.				Quality = 98%.		
	1,500			1,500			1,200				1,500				1,500		1,500				1,500		
	17			17			32				17				31		31				.17		
151	150.5	150	151	147	150.4	148	147.7	146.5	148.6	149.2	149.8	149.6	149.5	151	†149.4	†146.2	146	144.3	147.6	155.1	148.8	150	151.8
5.16	26.05	25.92	26.22	26.98	26.99	26.87	27.06	27.06	27.07	27.06	27.01	26.92	27.06	26.68	27.5	27.85	27.48	27.52	27.46	27.55	27.49	28.12	28.98
....	....	....	....	....	....	....	....	....	....	....	50.0	51.0	49.0	54.0	....	....	28	28	28	30	....	....	....
.98	.98	.98	.98	.98	.98	.98	.992	.994	.992	.991	....	....	....	....	.994	.995	....	....	....	....	.988	.975	.979
1,500	1,508	1,508	1,500	1,495	1,508	1,500	1,186	1,206	1,206	1,221	1,502	1,508	1,500	1,500	1,456	1,477	1,476	1,491	1,508	1,507	1,499	1,508	1,500
310	1,519	897	308	1,580	968	254	1,580.2	1,154.5	792.1	392.5	1,475	1,253	877	302	1,510.4	1,019.1	1,557.6	1,239.8	767.9	383.4	1,545	985	202
417	2,086	1,201	410	2,050	1,285	340	2,051.2	1,547.8	1,061.6	586.1	1,978	1,661	1,173	405	2,084.6	1,365	2,087.8	1,662	1,086.1	518.9	2,065	1,309	249.2
1,713	32,089	21,985	10,891	31,192	21,918	9,109	30,858	23,233	18,278	10,625	27,946	24,544	19,223	9,773	28,333	20,915	28,587	23,181	16,507	10,302	3,456	19,708	7,208
8.1	15.72	18.29	26.62	15.22	17.06	26.79	14.8	15.01	17.21	20.19	13.82	14.6	16.35	24.2	13.99	15.31	13.67	13.94	16.05	20.04	14.73	15.75	21.5
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
25	121	73	24	122	77	20	123	92	63	31	118	100	70	24	120	81	125	90	61	31	124	75	21
62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85

1,250 K. W.																				2,400 K. W. §		
							28 Inches.													27.5 Inches.		
							150													190		
		75° Superheat.					Dry Saturated.					75° Superheat.				100° Superheat.				190° Superheat.		
)		1,200					1,200					1,200				1,200				1,360		
		41					41			43		41				43						
.9	148.7	‡146.3	‡147.7	‡151	‡151.9	‡151.8	‡146.1	‡146.8	‡151	146.9	149	‡146	‡147.6	‡150.8	‡151.8	147	146.4	147.2	148.8	188	188	186
	26.95	27.1	27.1	27.15	27.07	27.15	28.06	28.1	28.05	28.1	28	28.1	28.1	28.05	28.05	27.95	28.02	27.97	28.02	27	27.5	27.98
	2	76	76	77	77	77	....	....	....	2	2	78	77	77	76	102.3	104	102.3	102	214	180	186
....	....	....	....	....	....	....	1.00	1.00	1.00	....	....	....	....	....	....	....	....	....	....	....	....	....
1,199	1,202	1,201	1,205	1,209	1,213	1,201	1,197	1,201	1,198	1,200	1,204	1,199	1,204	1,214	1,217	1,203	1,202	1,203	1,199	1,360	1,360	1,360
....	....	1,293.9	986.2	664.7	293.6	191	1,364	972	334.8	....	....	1,274.2	977.6	333.2	196.4	....	....	....	....	2,995	2,518	1,945
....	....	1,734.4	1,322	891	447.1	256	1,888.3	1,303	448.7	....	....	1,708	1,310.5	446.6	266.1	....	....	....	....	4,010	3,378	2,608
.7	1,004	....	....	....	....	....	....	....	....	1,578.2	911.5	....	....	....	....	1,808	1,655.6	1,296.4	815.4	....	....	....
9	15,241	23,908	19,108	14,181	9,170	6,734	25,639	19,334	9,295	21,286	13,337	22,504	18,180	8,420	6,300	23,180	21,302	17,009	11,671	44,236	30,356	30,367
....	....	13.78	14.45	15.9	20.51	26.2	14.02	14.91	20.71	....	....	13.17	13.87	18.80	23.68	....	....	....	....	11.02	11.57	11.83
13	15.18	....	....	....	....	....	....	....	....	13.49	14.63	....	....	....	....	12.82	12.86	13.09	13.70	....	....	....
	55	104	79	53	27	15	109	78	27	87	50	102	78	27	16	99	90	71	34	115	97	75
	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124

witnessed and verified by engineers of the staff of Julian Kennedy, Pittsburg, Pa.

§ Built by the Brown-Boveri Company.

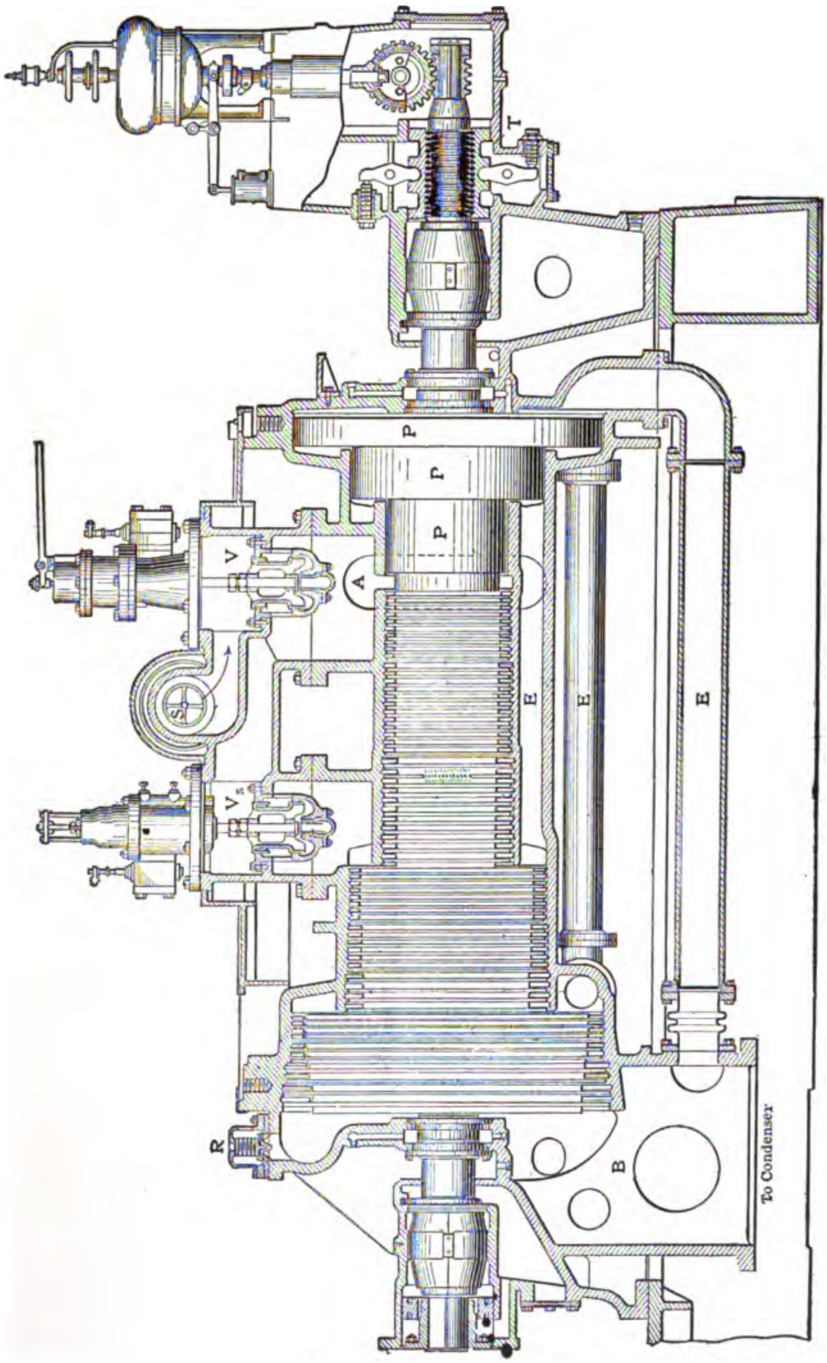


FIG. 10. Section of Westinghouse-Parsons Turbine (*Power*).

Reaction Turbines. — Fig. 10 is a section of a Parsons turbine as manufactured by the Westinghouse Company, of Pittsburg, which varies in several details from other Parsons turbines manufactured by other concerns in America and Europe. This Parsons or reaction turbine is so well known that it is not necessary to give a detailed description. On one end of the shaft there are a number of pistons so arranged that they will balance the pressure and remove the thrust from the rotary. These pistons are not used in the British Westinghouse Parsons turbine, where the steam enters in the

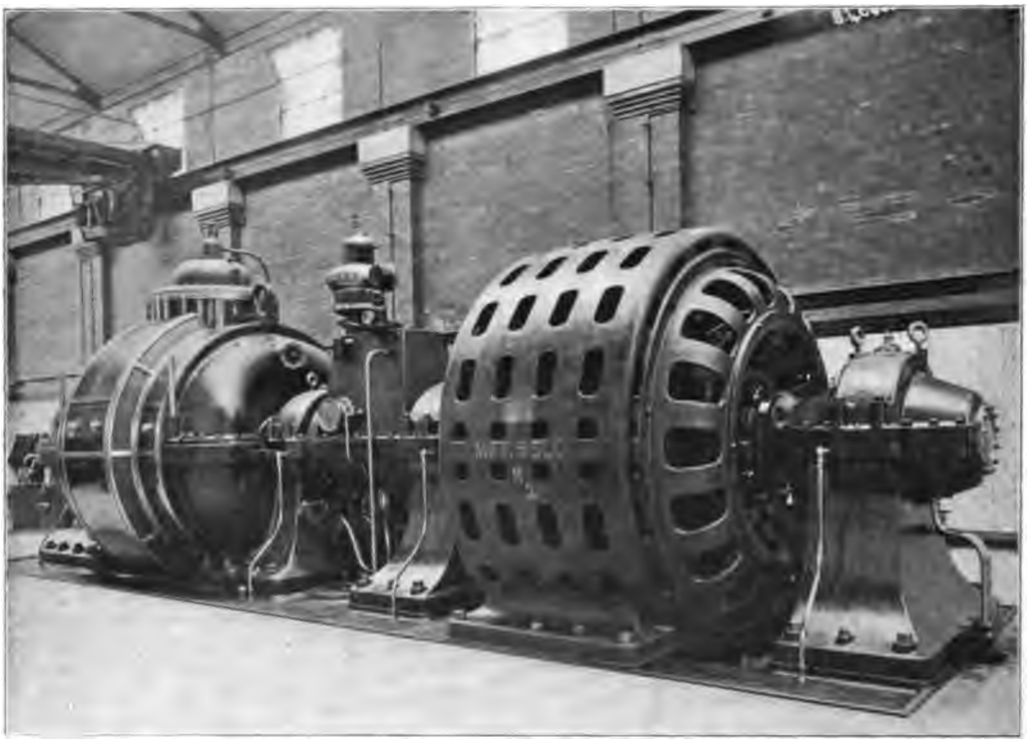


FIG. 11. 3500-K.W. Turbo Alternator, Neasden Plant, London.

center of the turbine case, expanding on both sides towards the exhaust ports and forming in reality a double turbine. See Fig 11.

The Brown-Boveri Company, Baden, Switzerland, succeeded first in building the Parsons turbine to operate with a remarkably low steam consumption. One of the most notable earlier installations is that of the municipal light & power plant of Frankfurt, where the steam consumption amounts to 9.11 pounds per I.H.P. hour under actual working conditions, operating with 162 pounds pressure and 572° Fahr. and approximately 28 inches vacuum. Fig. 12 shows a Brown-Boveri Parsons turbine of 6,500 K.W. capacity, as installed in the light and power station in Essen, Germany. It has one 5,000-K.W. A.C. generator and one 1,500-K.W. D.C. generator and the exciter mounted on the main turbine shaft. The entire length of the unit is 65 feet and

its greatest width over all is 8.5 feet, while the highest point is 8.5 feet above the top of the bedplate. The guaranteed steam consumption of this turbine of which there are

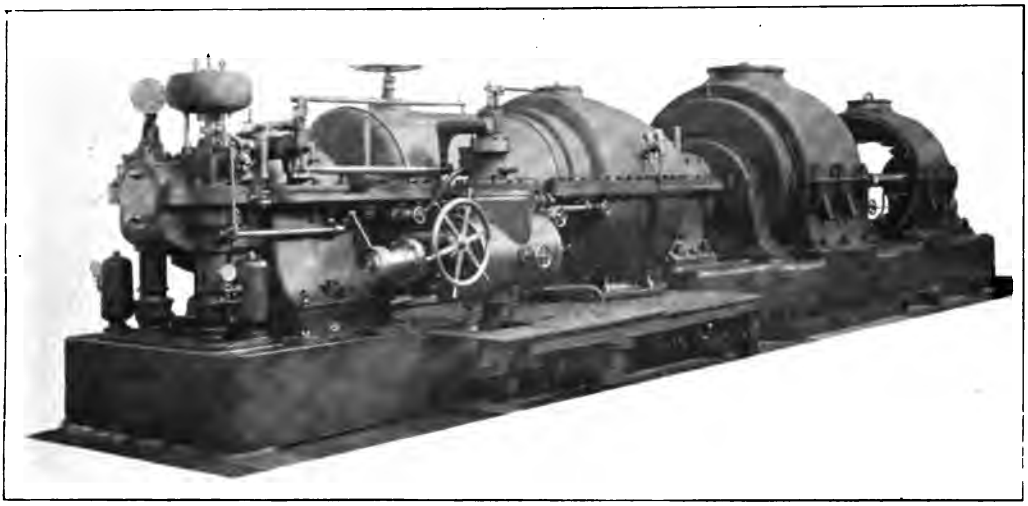


FIG. 12. 6500-K.W. Brown, Boveri Parsons Turbo-Generator at a Plant in Essen, Germany.

two installed, exhausting to one surface condenser, is 8.8 pounds per I.H.P. hour with 175 pounds pressure, 570° Fahr. total temperature and not less than 27 inches vacuum.

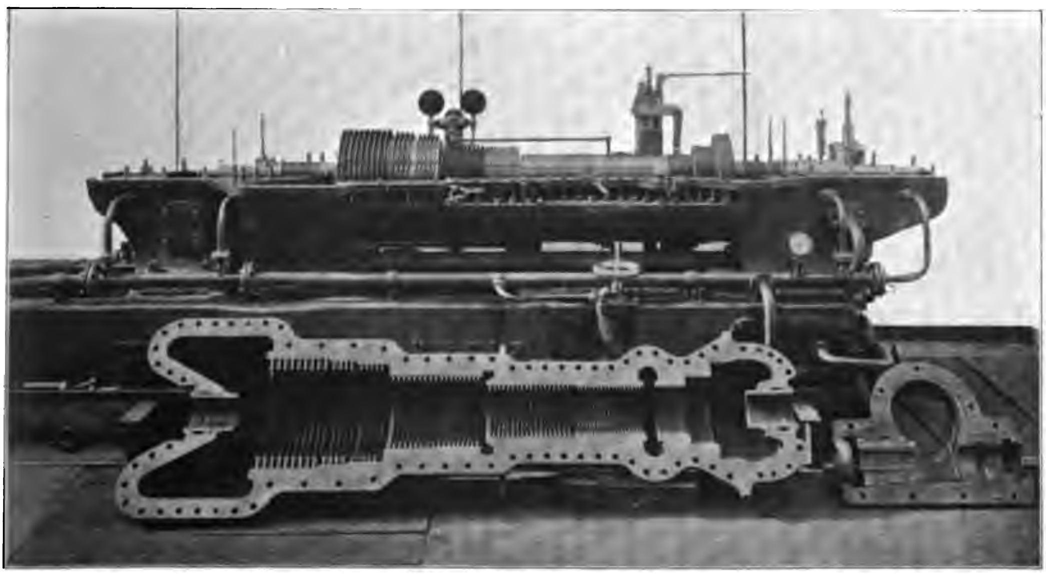


FIG. 13. Brown, Boveri Parsons Turbine with Casing removed.

These turbines are usually equipped with their own auxiliary machinery, motor driven, which operates with 1.5 per cent of the total output, bringing the total steam consumption up to approximately 9 pounds per I.H.P. hour.

As has already been stated in the introduction of this article, the Parsons turbine as well as several other types of turbines are provided with a secondary valve, admitting high-pressure steam to a later point in the expansion rings of the turbine, thus increasing the total output of the machine. By so doing the steam consumption is, however, increased.

CONDENSERS.

Principle. — The economy of a prime mover is increased as the temperature of the exhaust steam is reduced. If the exhaust is carried directly into the atmosphere, the ideal back pressure will be 14.7 pounds per square inch at sea level, or 212° Fahr.; if, however, exhaust is carried into a vacuum, produced by an auxiliary apparatus, say of 1 pound absolute, the temperature of the exhaust will be 102° Fahr. This is a difference of 110° Fahr. or an approximate gain of 33.5 B.T.U. per pound of steam; since an engine which exhausts directly into the atmosphere has a back pressure of a few pounds above the atmosphere, due to friction, the gain may be even greater than this. In order to create a vacuum into which to discharge the exhaust steam, a condenser is applied which extracts the latent heat from the steam.

Vacuum is measured in inches of mercury, 30 inches being assumed as a perfect vacuum. This value varies according to atmospheric conditions, sometimes being as low as 29 inches and again as high as 31 inches. It will therefore be seen that this is not an accurate means of measurement. A more accurate system of measuring is expressed in percentage of the atmospheric pressure. With this method two instruments are required or else an instrument with two springs, one for barometric readings and the other for vacuum reading in percentage.

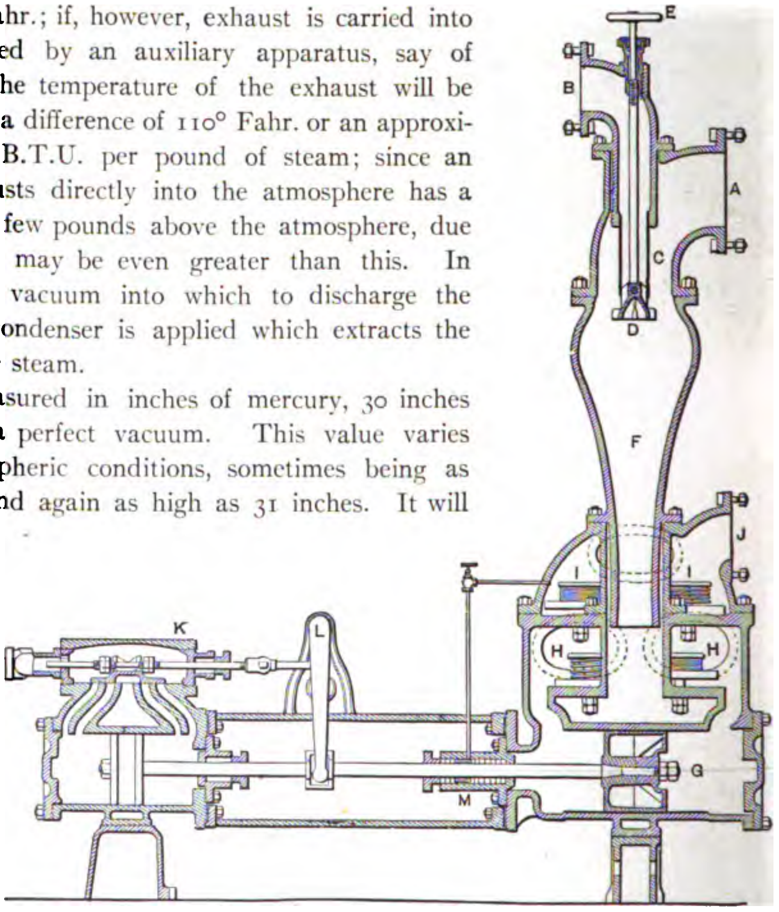
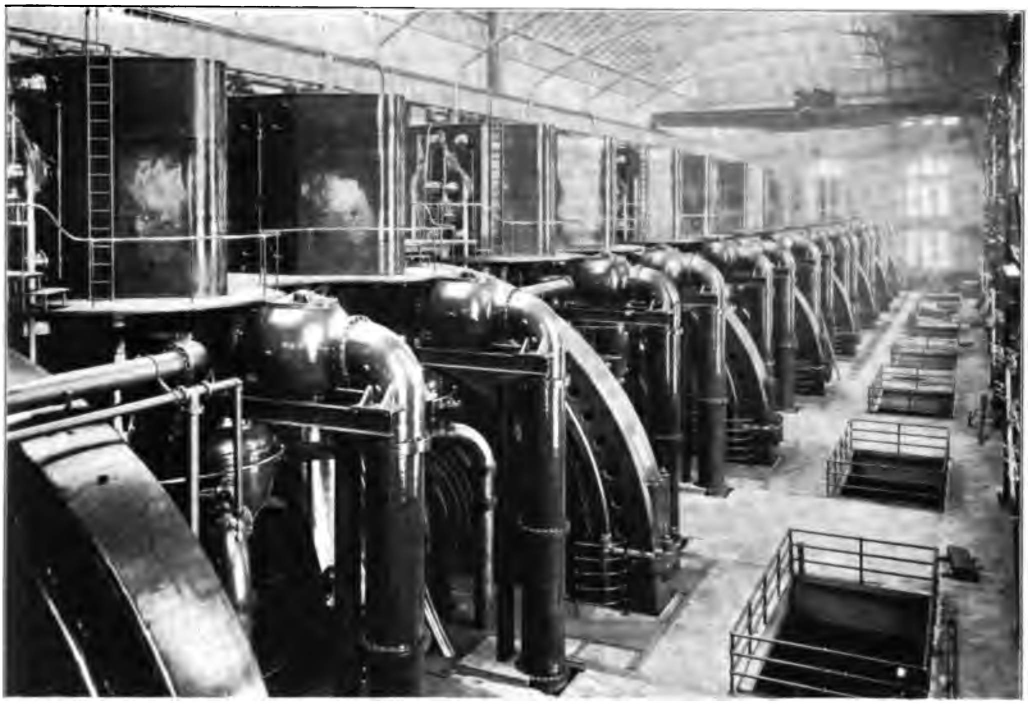


FIG. 1. Worthington Jet Condenser.

Classification. — Condensers may be divided into two main classes, viz., jet and surface condensers. In the former water is injected directly into the exhaust steam, which gives this apparatus its name, jet condenser. The surface condenser is so called



New Condenser Apparatus at the 74th St. Plant, New York. (Original Condenser of the motor driven, air pump type.)

Surface Condenser Plant (motor driven) Tramway Power Plant at Pinkston, Glasgow.

for the reason that the condenser water is used to cool a number of tubes, the exhaust steam coming in contact with the exterior surface of these tubes.

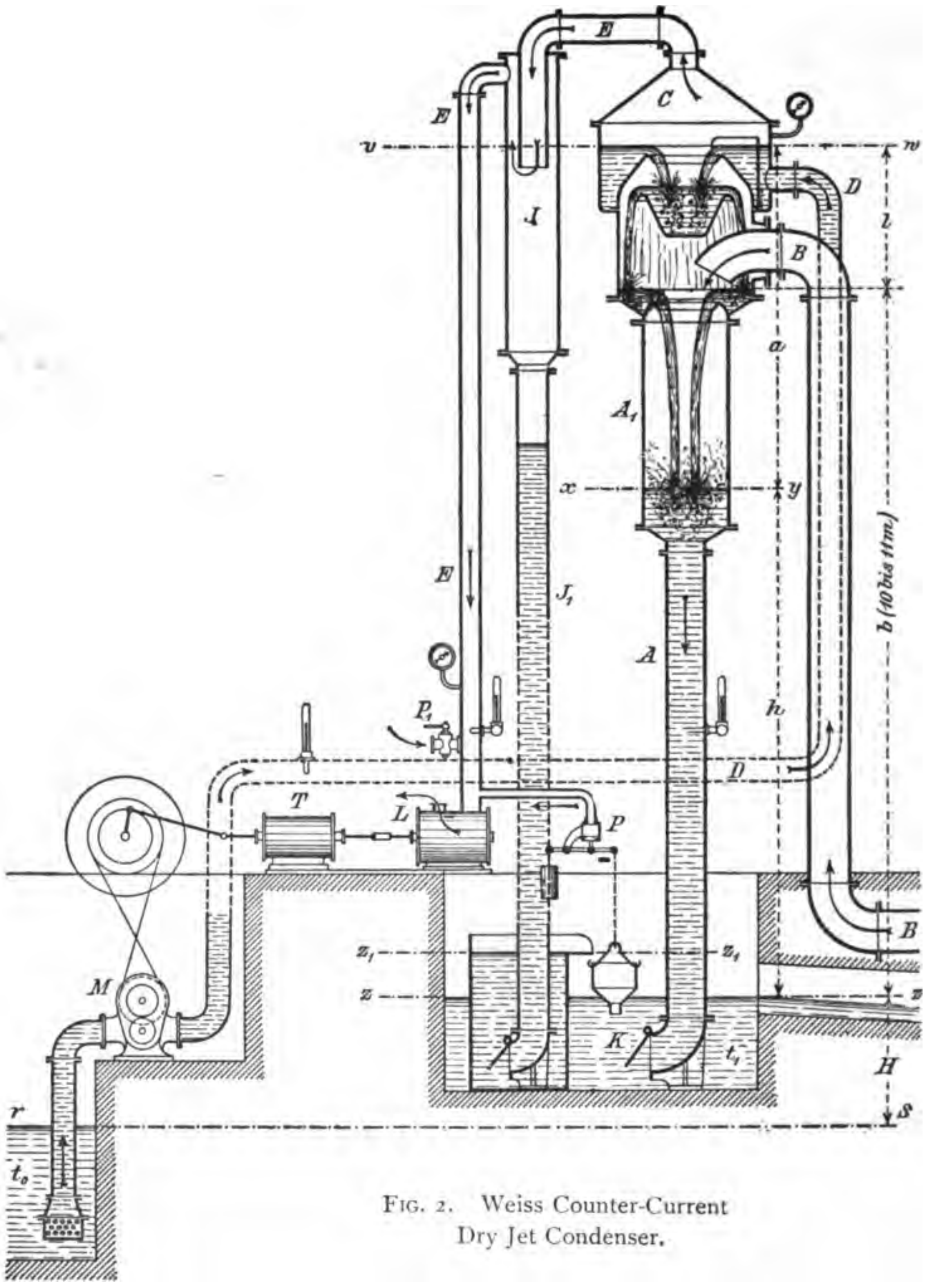


FIG. 2. Weiss Counter-Current Dry Jet Condenser.

The surface condenser may be sub-classified as parallel and counter-current flow types. These classifications are self-explanatory. In the former case the water will flow in the same direction as the steam, and *vice versa.*

The jet condenser may be sub-classified as "wet" and "dry." The former is so designed that the air and vapor are discharged with the condenser water; the latter is supplied with a separate so-called dry vacuum pump for the removal of air and vapor.

The wet jet condenser may be applied as a barometric condenser, or have its discharge directly connected to the suction of a combined circulating and air pump, as shown in Fig. 1, while the dry type is exclusively built as a barometric condenser (Fig. 2).

The dry jet condenser is also classified as parallel and counter current; if, for instance, the flow of air and vapor is opposed to the flow of water, the condenser

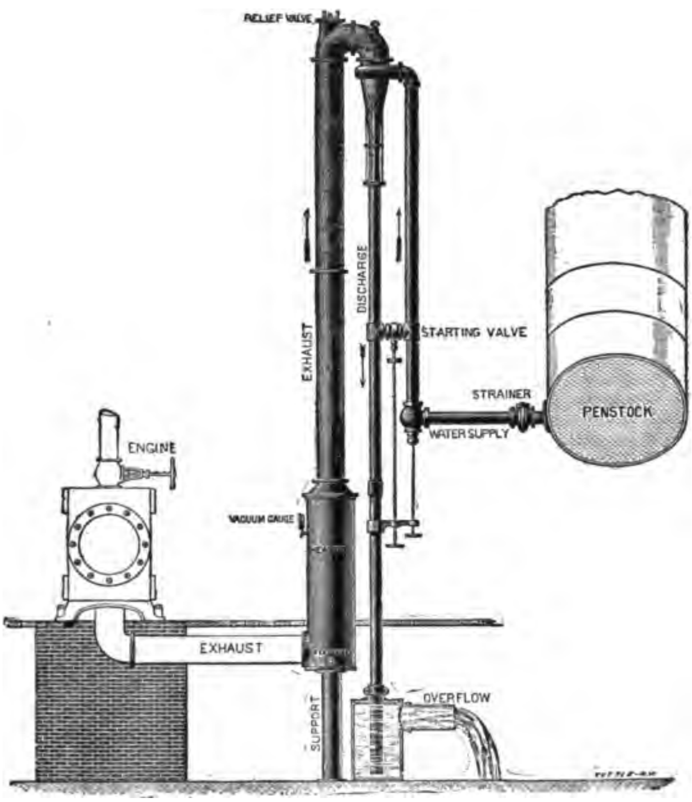


FIG. 3. Bulkley Condenser Supplied from a Natural "Head" of Water.

is of the counter-current type, and *vice versa*. Another application of the barometric wet jet condenser is known as the siphon condenser, Fig. 3. This design is very economical, as it requires no moving parts, provided that a natural water supply is at hand of not less than 15 feet above the hot well, which must be 34 feet below the condenser vessel. After once being started this condenser is entirely automatic. With any greater lift the operation will not be satisfactory and a supply pump is required. It is not necessary to use an air pump with this type of condenser, for the condensation takes place directly above a contracted neck, wherein is produced

so high a velocity of the jet that the air and vapor are carried down with the water into the hot well.

Application. — In laying out a power plant careful consideration should be given to the local water supply, to determine whether it will be economical to install condensers. This depends also on the size of the plant, type of machinery and price of coal.

When the plant is so located that it is difficult to obtain water other than from the city mains, special provision for re-cooling the discharge may be applied. A condition similar to the above would be where plant was located on a small canal, from which water could be drawn during certain hours of the day only. In cases like this the water would be collected in a reservoir and re-cooled by means of a cooling tower.

It is frequently claimed that it is not economical to install a condensing apparatus in small plants. This depends largely on the type of prime mover, whether turbine or reciprocating engine. High vacuum with a turbine is essential to secure economy, while with a reciprocating engine the benefit of high vacuum is less. Furthermore, the percentage of steam consumption necessary to operate the condensing apparatus in a small plant is much larger per unit capacity than that required in a large plant.

Where fuel and labor are cheap the saving in steam produced by the condenser may not save enough money to pay a sufficient percentage on the investment or first cost of the apparatus.

Condenser Water Required. — The amount of water required to thoroughly condense the steam is dependent upon two conditions, the total heat and weight of the steam, and the temperature of the injection water.

To estimate the volume of water for condensing purposes under any specific conditions, the following formula will be of assistance:

Given: I = Temperature of injection water.
D = Temperature of discharge water.
S = Total heat (sum of sensible and latent heat) of the steam at the pressure at which it leaves the engine.

Then: $\dfrac{S - D}{D - I}$ = Unit weights of injection water required per unit weight of steam.

Example: $I = 70°$ Fahr.
$D = 110°$ Fahr. with a vacuum of 26 inches.
$S = 1{,}190$ units of heat.

Hence: $$\frac{1{,}190 - 110}{110 - 70} = 27.0.$$

That is, the weight of the injection water required will be 27.0 times the weight of the steam exhausted.

Upon a test with no air leaks it might be possible to carry the discharge water at a higher temperature than 110°, thus reducing the quantity of condensing water

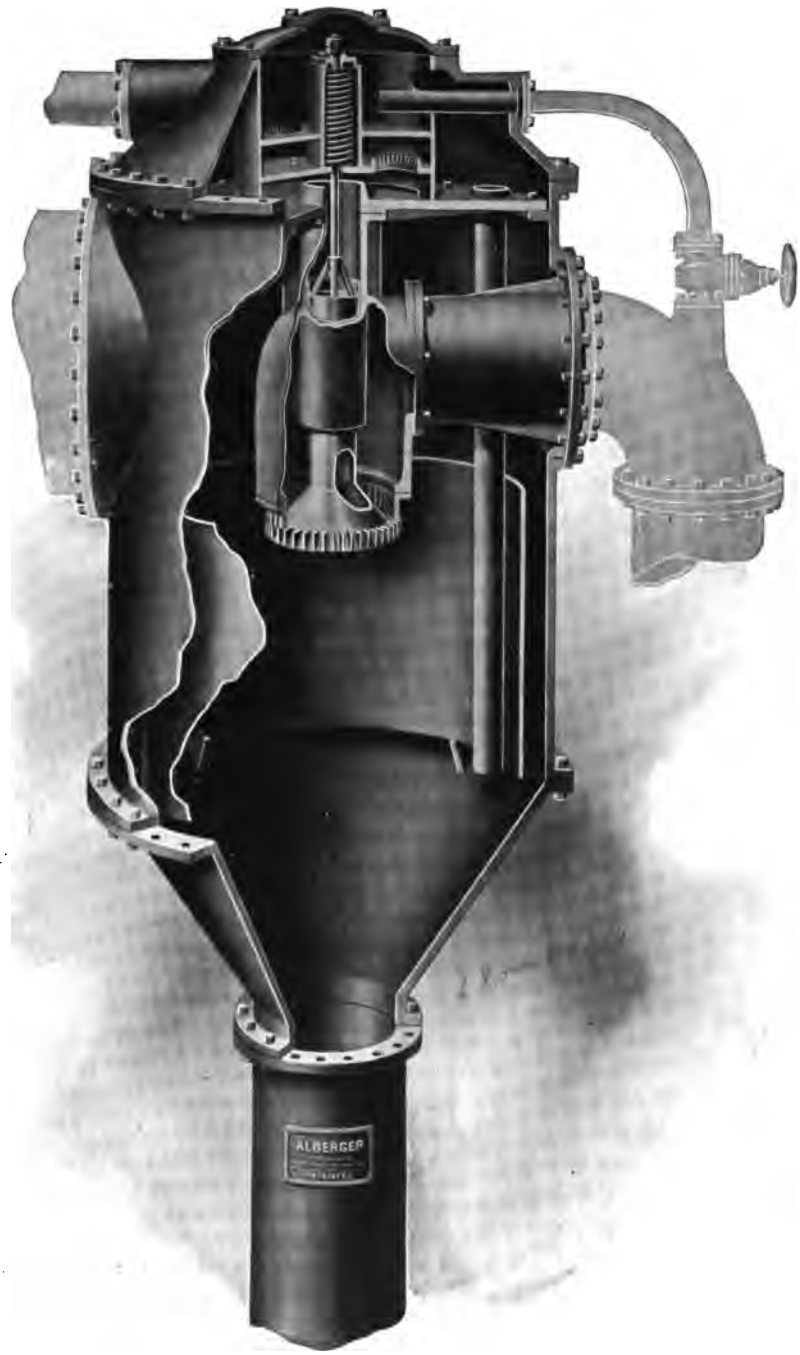


Fig. 4. Alberger Barometric Counter-Current Condenser.

required. As a general rule, it may be stated that a temperature of discharge water within 15° of the temperature corresponding to the vacuum in the condensing chamber is as high as can be expected in actual service. The difference is due to the partial destruction of the vacuum by the air present in the condenser.

Jet Condenser. — The accompanying illustration, Fig. 4, represents the Alberger barometric condenser, which is of the counter-current type. It will be noticed that

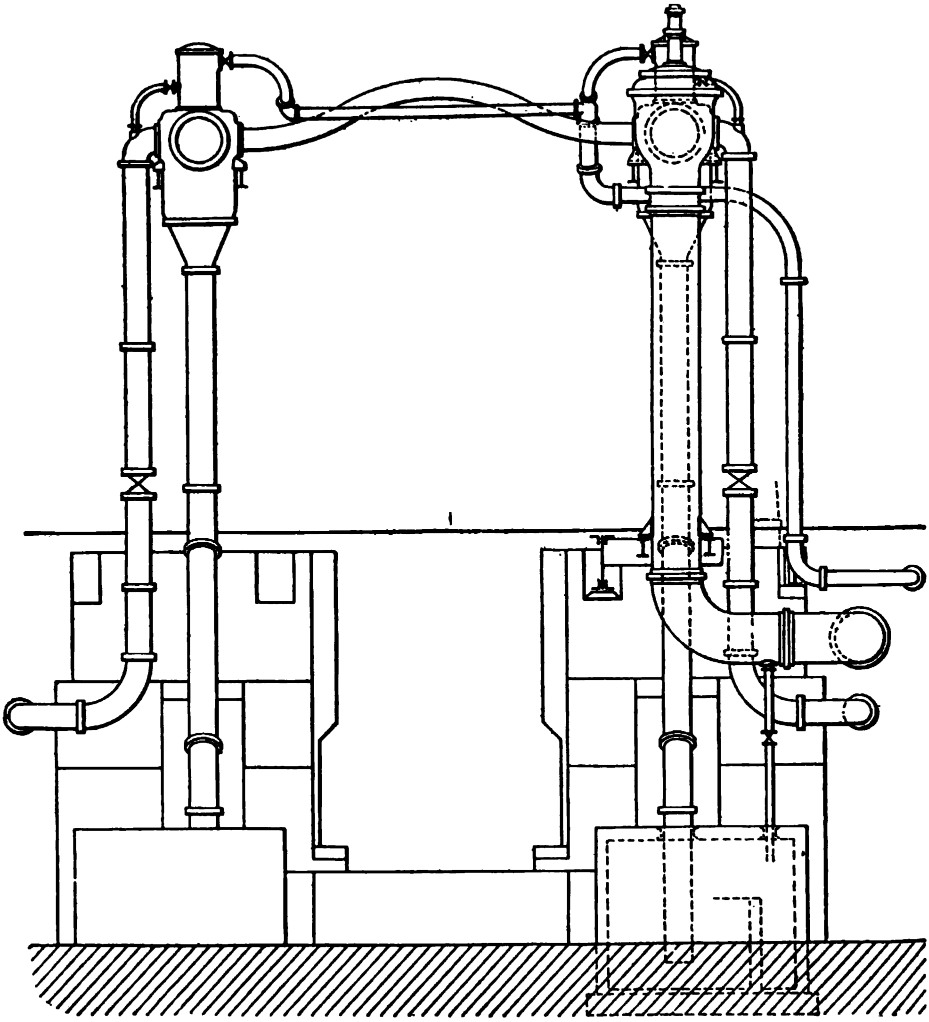


FIG. 5. Two Alberger Condensers Connected to One Twin Compound Engine. (*The Engineer.*)

the water is brought into the vessel on the right-hand side, and passes downward over a cone so arranged that it divides the water into a fine spray, which comes in contact with the steam entering from the opposite side. The air and vapor rise through the hollow cone to the upper part of the vessel into an air cooler, where they come in con-

tact with a small percentage of the condensing water, thus reducing the air temperature before it is drawn away by the dry vacuum pump. It will be noticed that the spray cone is suspended on a spring, so that if the engine is running under a light load and a small amount of water is passing through the condenser, it will be as properly sprayed as if a larger amount were passing through, which would compress the spring by forcing the cone downward, increasing the escaping area. This, as well as all other barometric condensers, must be placed not less than 34 feet above the overflow of the hot well.

Fig. 5 represents an Alberger condenser unit, connected to a twin compound engine. Nine of these were installed in the 59th Street power station, New York City. Each of these condensers receives the exhaust from one low-pressure cylinder, and as both of these condensers are operated from a single dry vacuum pump and a single circulating pump, it is of importance to maintain equal vacua in both condensing vessels. It will be noticed that the air pipes

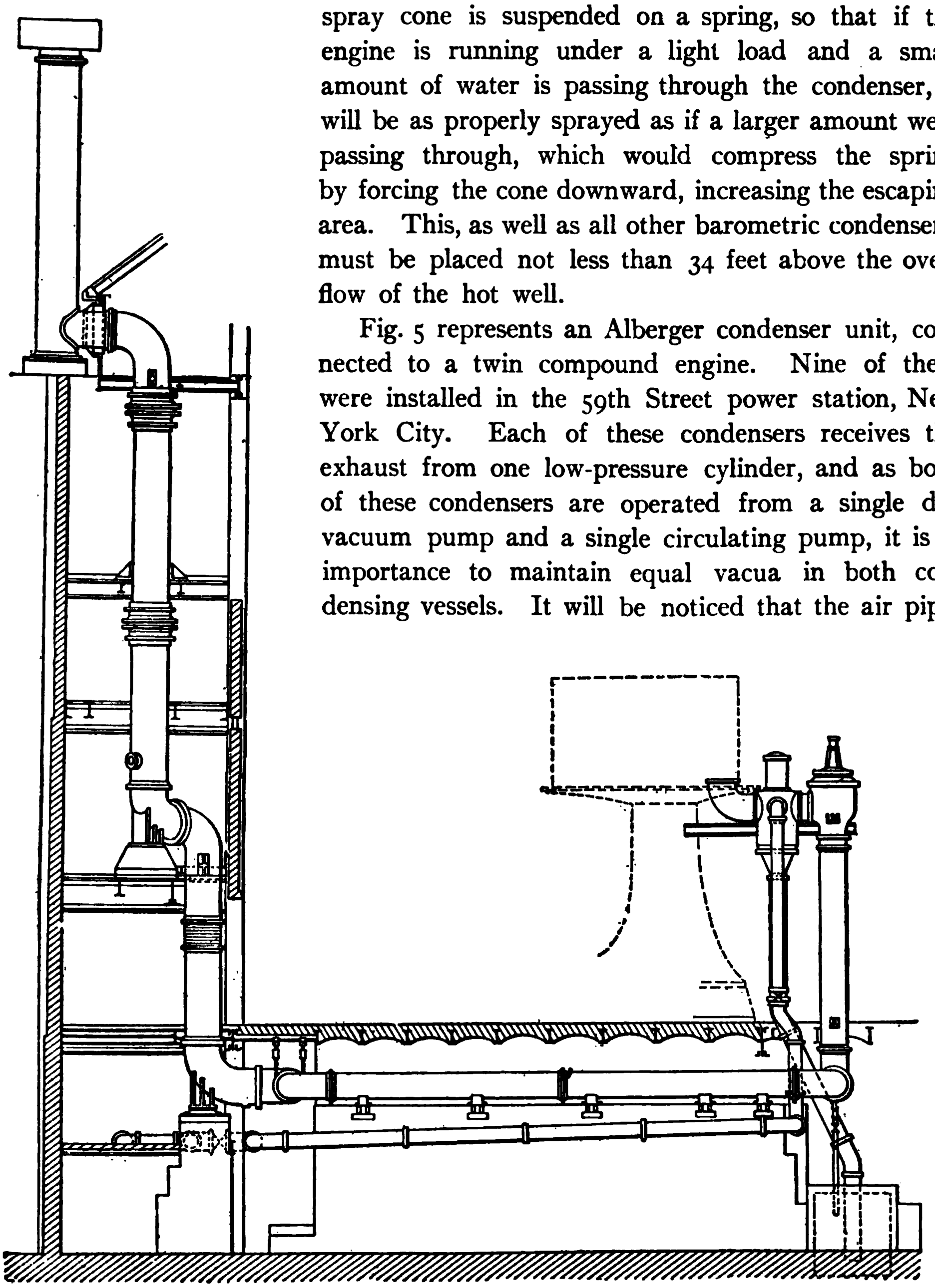


FIG. 5a. Side Elevation of Fig. 5. (*The Engineer.*)

from both condensers are connected to one suction pipe; this also pertains to the circulating water supply, although it is not shown in this cut. An equalizing pipe

connects both vessels, still further assisting in establishing an equal vacuum. The side elevation of this same installation is seen in Fig. 5a; joined directly to the

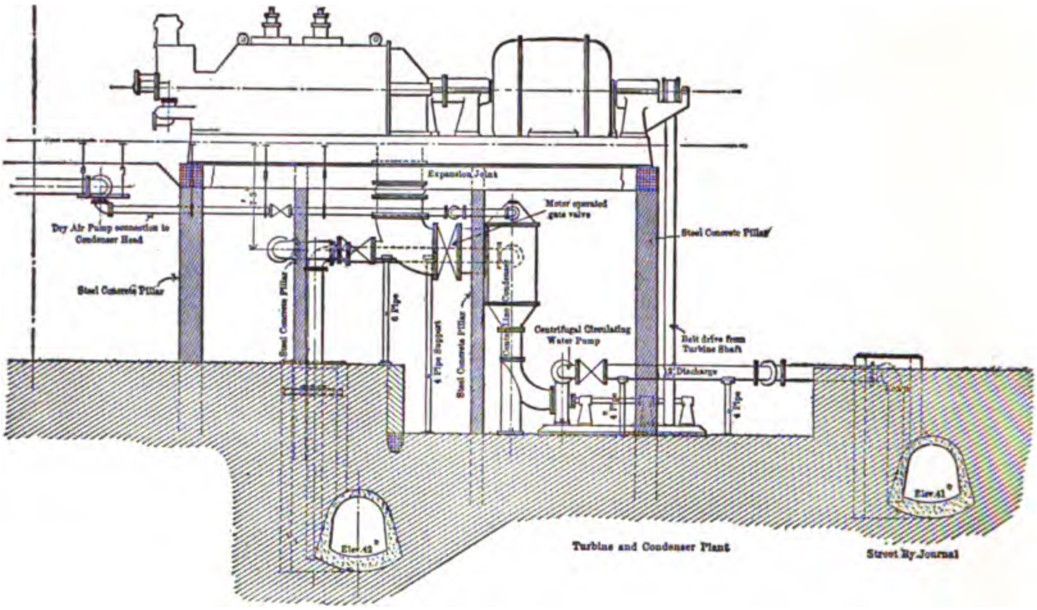


Fig. 6. Condenser Arrangement with a 6,000-K.W. Turbine at the Delaware Ave. Plant, Philadelphia. Note arrangement of the Centrifugal Pump.

condenser is the atmospheric relief valve, to discharge the exhaust directly to the atmosphere automatically should the vacuum be broken.

The tail pipe of a barometric condenser must be submerged in the hot well to a sufficient depth so that the amount of water between the bottom of the pipe and the overflow will not be less than 1½ times the amount contained in the tail pipe.

Surface Condenser. — The surface condenser consists of a large number of brass tubes usually ¾ or 1 inch in diameter, and interconnected at their ends by so-called head plates, in which the tubes are packed and kept tight by a stuffing box and screw gland. The circulating or cooling water passes through these tubes at a velocity of from 350 to 500 feet per minute, while the steam passes around them, being confined by the enclosing shell of the condenser, which is generally made of cast iron, while in Europe wrought iron shells are frequently employed with large size condensers.

The condenser is rated by the condensing surface contained in the tubes, and under ordinary conditions 3.75 to 4 square feet are allowed per kilowatt of turbine capacity. This latter figure may, however, be increased in tropical climate, where the temperature of the cooling water is high.

With the steam turbine it pays to install condensers large enough to create high vacua, for the efficiency of the turbine depends largely on the exhaust pressure. In order to assist in obtaining a high vacuum with a comparatively small condenser, Parsons, the inventor of the turbine of that name, designed a vacuum augmenter. It

consists practically of a steam injector, as will be seen in Fig. 7, located in the suction pipe to the air pump. This, of course, adds to the steam consumption, and it is claimed

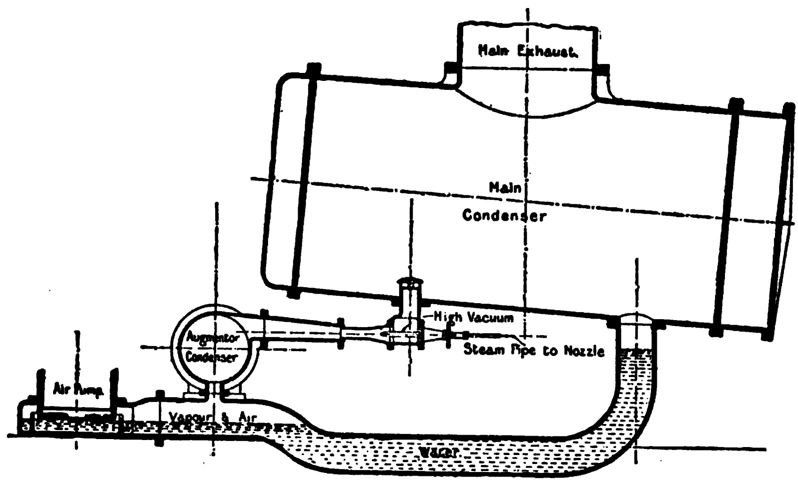


FIG. 7. Arrangement of Parsons Vacuum Augmenter.

that this addition amounts to 1 per cent of that of the turbine; the heat of this steam, however, is not entirely lost, for it raises the temperature of the hot well water and con-

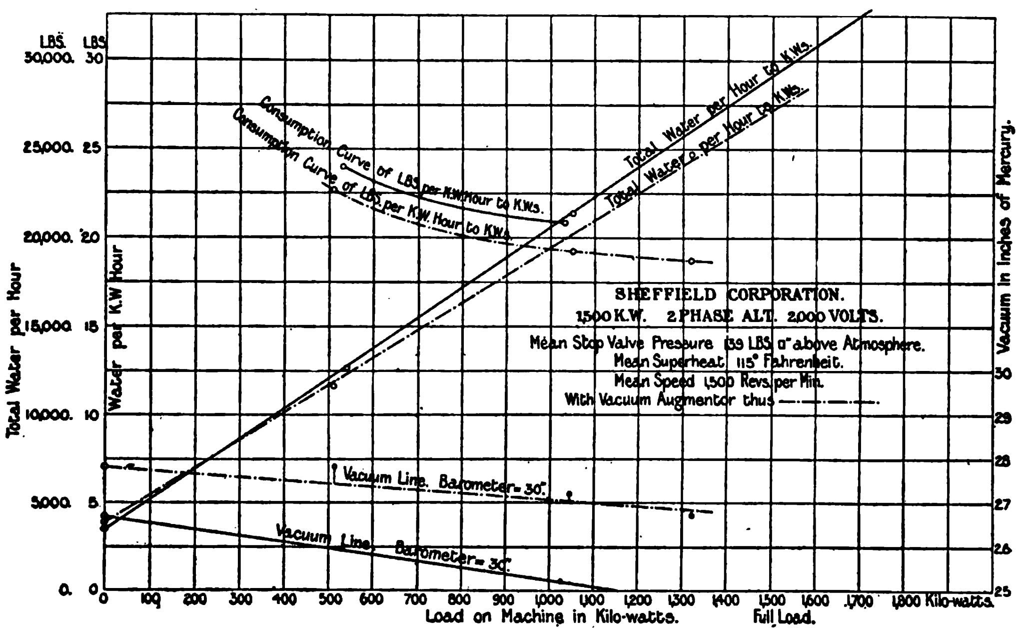


FIG. 8. Effect of Parsons Vacuum Augmenter.

sequently that of the boiler feed, provided that the water is not allowed to lie in the hot well long enough to radiate this heat. Fig. 8 * shows the effect of a Parsons aug-

* "Journal of the Institution of Electrical Engineers."

menter as installed in conjunction with a 1,500-K.W. turbine, in the Sheffield Corporation power plant, the amount of steam consumed by the augmenter is included in the total steam consumption of the turbine.

As previously stated, the large number of turbines which have been installed has greatly increased the use of surface condensers. The reason for this is that the exhaust

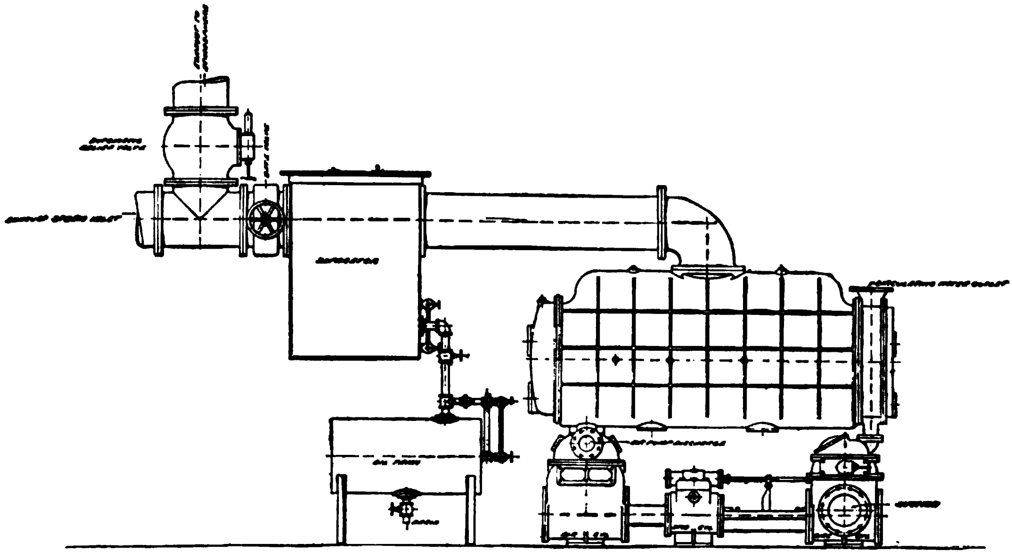


FIG. 9. Arrangement of Baker Oil Separator and Wheeler Surface Condenser Mounted upon Combined Air and Circulating Pumps.

steam of the turbine contains no oil, and therefore the water of condensation may be returned to the boilers, instead of being wasted, as is the case with reciprocating engines, unless some apparatus to remove the oil from the exhaust steam or from the hot well water is applied. A device of this kind, and its pipe connections, is shown in Fig. 9. It will be seen that the oil separator is placed between the engine exhaust and the condenser inlet. The oil is removed from the steam in the separator and flows by gravity into the receiver tank, whence it is removed when the tank fills. This cut also shows the location of the atmospheric relief valve. The gate valve shown between the relief valve and the oil separator is for cutting out the condenser in case of repairs.

A cross-section of this particular condenser, which is of the Wheeler type, is shown in Fig. 10. In this cut the condenser is mounted on a combined air and circulating pump, and is of the counter-current type; the circulating water entering, as shown, at the lower right-hand corner, travels in an opposite direction from the steam entering at the top, so that the hottest steam comes in contact with the hottest water and *vice versa.* The air pump handles all the condensed steam as well as the air and uncondensed vapor discharging into the hot well tank, from which the boiler feed may be taken. When it is desirable to use the circulating water over again, the discharge of the circulating pump may be piped to a cooling pond or tower. This subject will be treated in a succeeding article.

Plants equipped with the Curtis turbine are frequently provided with a so-called "base condenser." In this case the turbine is mounted directly upon the condenser. This forms a very compact apparatus, requiring much less floor space than a separate condenser, and is therefore used to a considerable extent. Its disadvantage is that the condenser cannot be repaired without shutting down the turbine. This type, as well as all others, should be provided with an atmospheric relief valve; if, however, anything happens to the base condenser, so that the turbine discharges to the atmosphere, the circulating pump should continue in operation to prevent the packing around the tubes from being burned out. If this packing is injured the condenser will leak and the vacuum be destroyed.

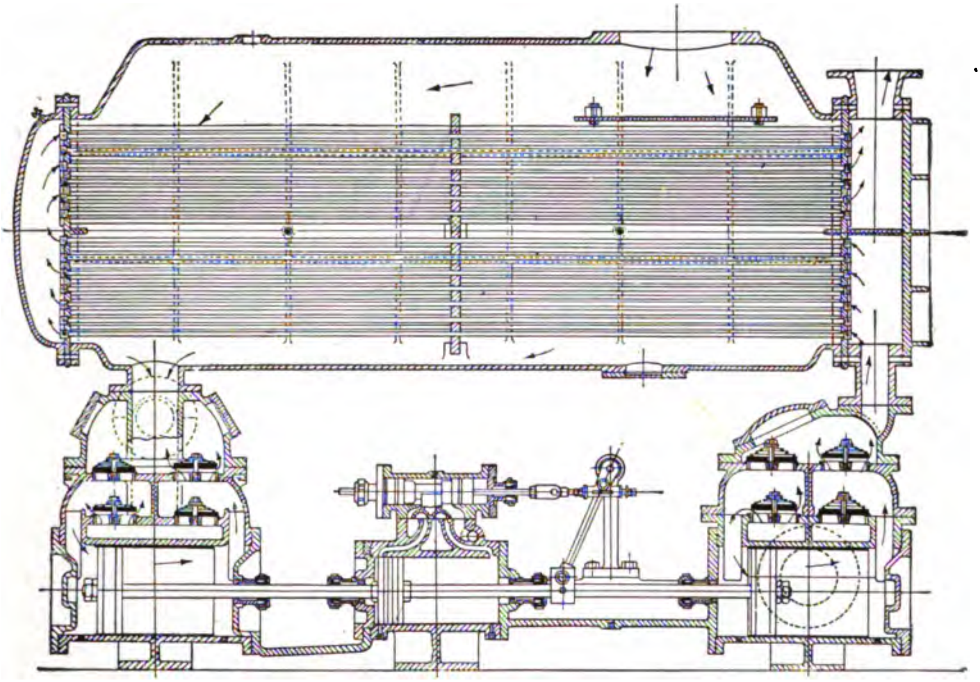


FIG. 10. Surface Condenser Mounted on Combined Air and Circulating Pump of the Wheeler Condenser and Engineering Co.

When the exhaust from auxiliary machinery is not enough to raise the temperature of the boiler feed water to a sufficiently high degree, or where motor-driven auxiliaries are used, the upper row of tubes near the steam inlet may be so arranged that the discharge of the boiler feed pump will pass through them, thus utilizing the condenser as an auxiliary feed water heater. A similar arrangement of heater in the engine exhaust is shown in Fig. 3.

Fig. 11 represents a complete condensing unit of the Worthington pattern. It will be noticed that in this type of apparatus there are three separately driven pumps, viz., circulating pump, dry vacuum pump and hot well pump. The two former are

steam driven, while the latter is motor driven. It is frequently claimed that auxiliary machinery can be more economically driven by steam than by electricity, and that the liability of break-down is increased in the latter case. It is the author's opinion that the above condenser layout would be more systematic if all of the pumps were steam driven or *vice versa.*

Care should be taken that the hot well pump be located at least three or four feet below the hot well. This precaution should be taken in order to secure a hydrostatic head to the suction of the pump, so that the hot water will fall in a solid body, thereby overcoming to some extent the high vacuum which is on the top of the hot well and securing a constant flow to the pump suction.

The best practice is to provide the surface condensing plant with separately driven circulating pump, dry vacuum pump and hot well pump. These pumps should be grouped around their prime mover in order to form a complete unit system, so as to facilitate easy operation. Modern power plants are always equipped with one or two prime movers in reserve, and should any pump require repairs the complete unit will be shut down and one of the reserve units cut in.

Central Condenser. — Frequently two or more prime movers are connected to a common condenser, called a central condenser. This practice usually results in long exhaust mains. Care must be taken that a condenser of this character be placed as near the exhaust ports as possible, in order to minimize leakage at joints and friction. All engine connections should be properly valved or the leakage will be considerably increased through the engine stuffing boxes when the engine is shut down. Some barometric condensers are especially adapted to withstand large variations in load; a type of this class is shown on Fig. 2, representing the Weiss counter-current system.

The central condensing system, be it either surface or jet condenser type, may control the entire plant, provided the plant is not too large, in which case three or four prime movers may be grouped on one central condensing system. This latter scheme has been used in the Kingsbridge plant in New York.

Where a single central condensing system is used in a plant of large capacity, it is advisable to install emergency pumps, so that if one or more of the pumps break down it will not be necessary for the engines to exhaust into the atmosphere. The efficiency of the central condensing system is higher than that of the unit condensing system, because the large units employed operate on a smaller steam consumption; it also needs less attention.

Vacuum Breaker. — A vacuum breaker should be installed in the piping of the vacuum pump, as a means of safety. If any accident should happen to the wiring system, or if for any reason the load should be cut off, the engine would be liable to run away with a large vacuum on the exhaust. The arrangement for breaking the vacuum is very simple: a small pipe is connected to the vacuum pump suction pipe, to which is attached a valve, provided with a screen, admitting atmospheric pressure to the condenser.

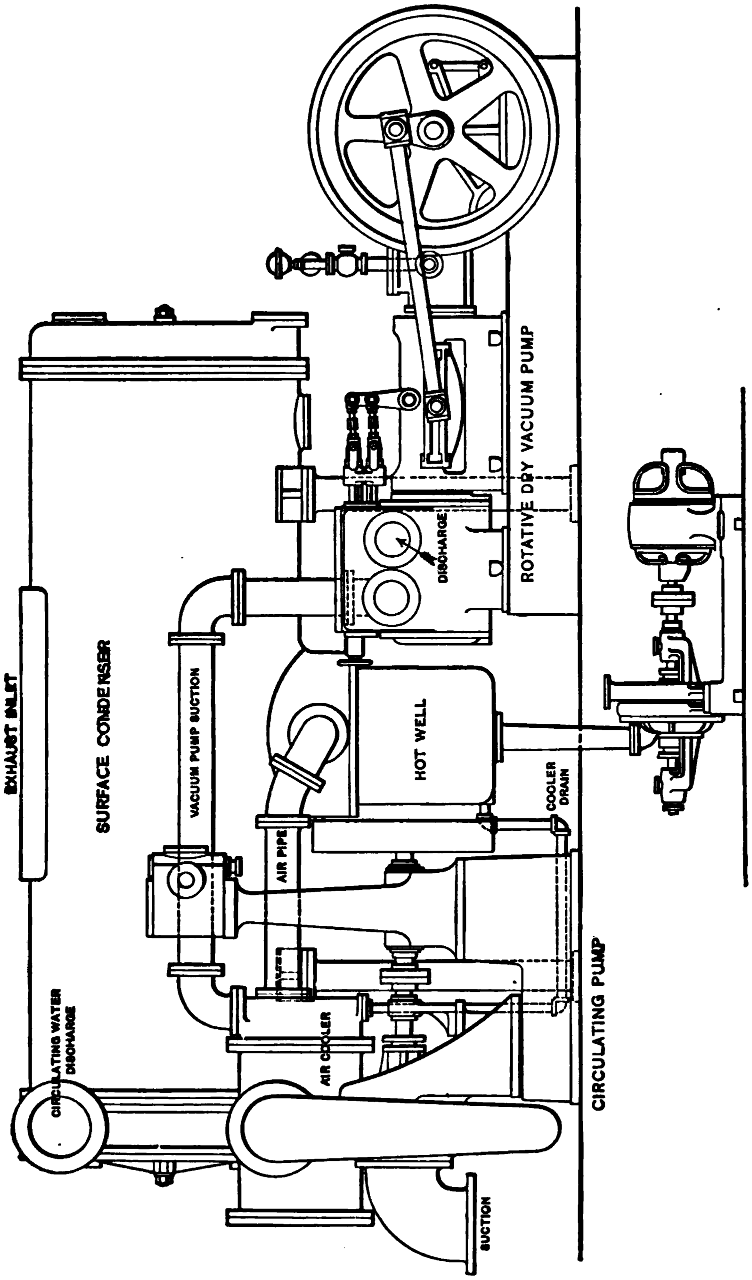


FIG. 11. Worthington Condenser Plant.

Cooling Towers.—The location of power plants often limits the amount of condenser water that may be obtained. One is therefore forced, when the plant is run condensing, to cool the condenser water, and use it over and over again. This can be done either by a cooling tower or a pond; the latter will be described under separate heading.

Cooling towers are either wooden, as commonly used in Europe, or of steel as is the practice in America. A more recent method is to build them of reinforced concrete. This, however, has not been done to any considerable extent.

Cooling towers may be classified as natural draft and forced draft. The latter are equipped with one or more fans. This type is generally used in America,

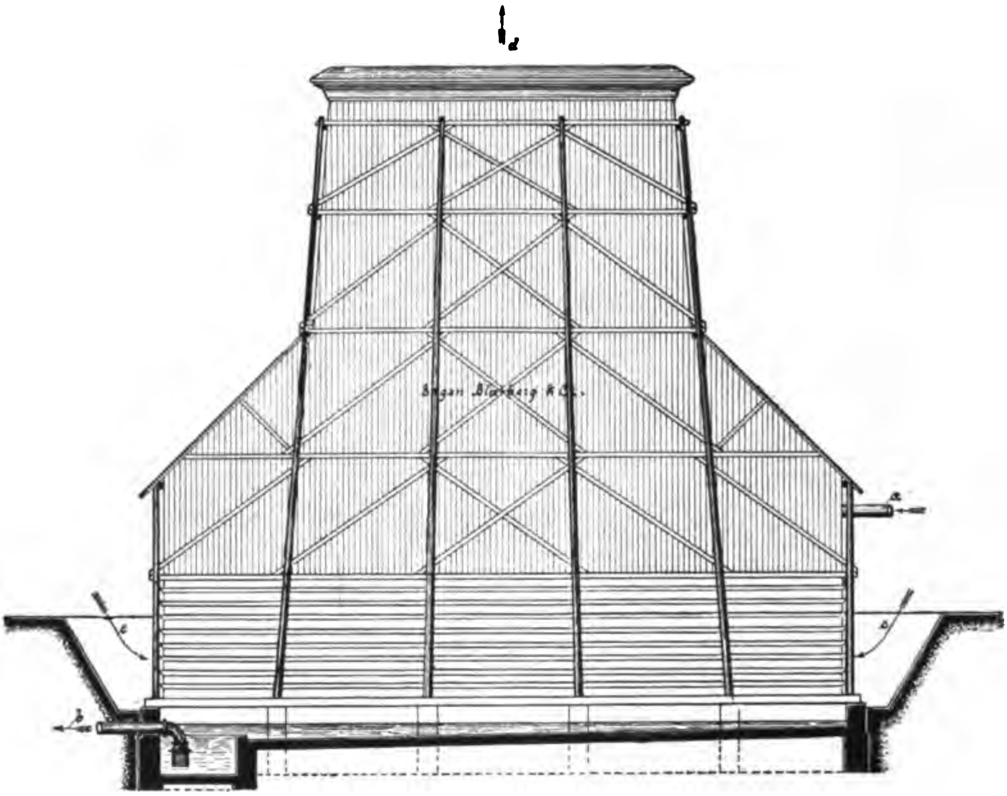


Fig. 12. Typical German Cooling Tower.

and is preferable where ground space is limited. Its height is also less than that of the natural draft type. The steel forced-draft tower requires a ground area of from 1.1 to 1.3 square feet per 100 pounds of steam condensed; the wooden forced draft-tower requires from 1.3 to 3 square feet for the same amount of exhaust steam. This large difference is due to the difference in design and the cooling effect of the iron. The natural-draft cooling towers are generally built of wood and have a height of from 40 to 75 feet. The area required for these towers amounts to

from 6 to 8.5 square feet per 100 pounds of exhaust steam. These figures are based on practical experience and average working conditions. The circulating water is taken at a temperature of from 60° to 65° Fahr. and the amount of cooling water per pound of steam condensed is from 30 to 35 pounds with an atmospheric temperature of from 50° to 65° Fahr. and an average humidity.

From the above it may readily be observed that the size of the cooling tower depends on many existing conditions, such as the amount of steam to be condensed, the amount

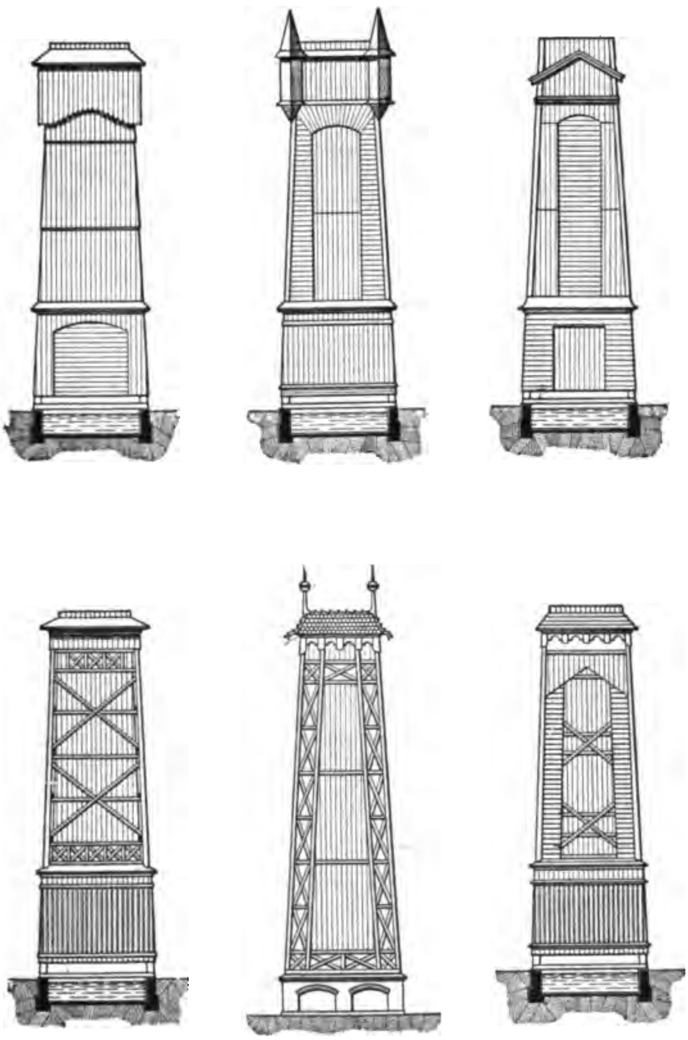


FIG. 13. Architectural Design of Cooling Towers.

and temperature of condenser water, the temperature and humidity of the atmosphere and the difference in temperature of the circulating water created by the cooling tower.

In order to avoid the pumping of the condenser water over the cooling trays in the cooling tower, the discharge of the condenser must flow by gravity above the trays. This may mean in some cases that the cooling tower must be sunk below grade level, an example of which is shown in Fig. 12. This type of the tower itself is typical of Continental practice. It is of cheap construction, being made entirely of wood, and is very bulky in appearance and seldom if ever in harmony with the architectural

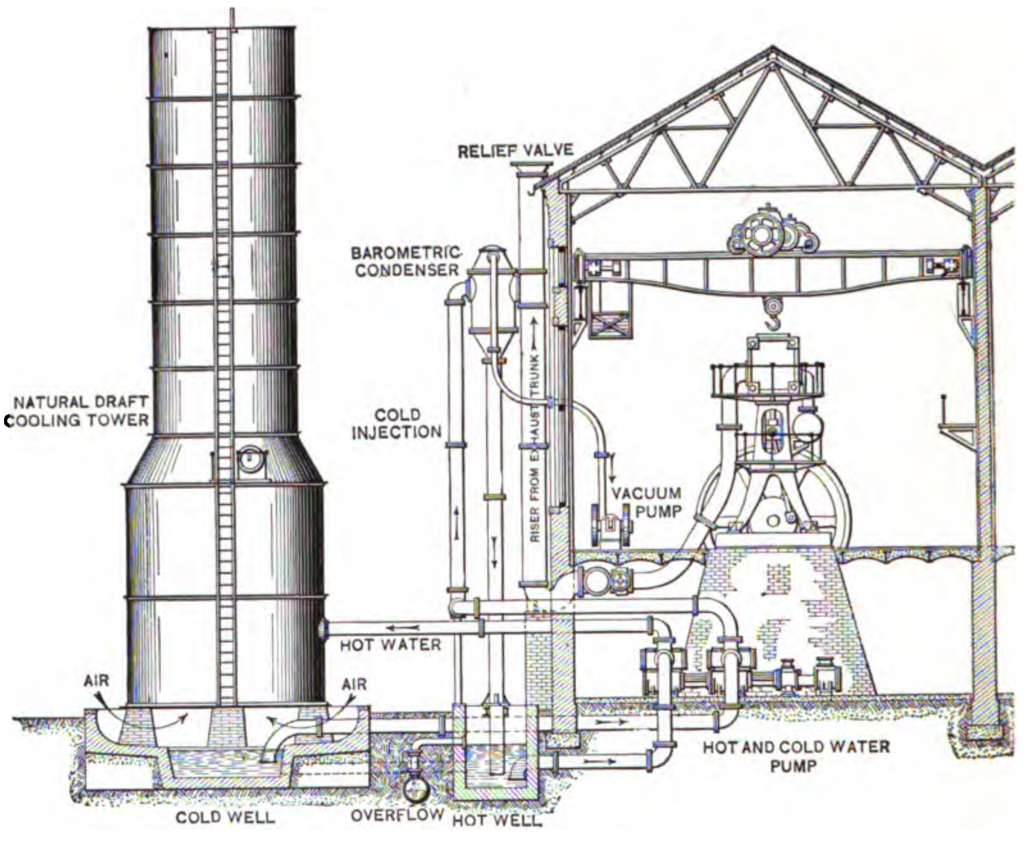


FIG. 14. Alberger Barometric Condenser and Natural-Draft Cooling Tower.

design of the plant building. It is possible, however, to give an artistic finish to the tower, as will be seen in the accompanying illustration, Fig. 13. These towers were designed by H. Friederichs & Co., Logan, Germany. In any case the water must be pumped before or after cooling.

A typical American layout for condenser and cooling tower is shown in Fig. 14. This illustration represents an Alberger condensing plant. The figure is clear and self-explanatory. Fig. 15 is a cross-section of the Worthington forced-draft cooling tower; it will be seen that the condenser discharge enters near the bottom of the tower

and is pumped up through a standpipe to a distributer. This distributer consists of a number of arms, constructed of perforated pipes; these perforations are all on one side, and the velocity of the water discharging through these holes causes the distributer to revolve. The entire cross-sectional area of the tower is filled with a large

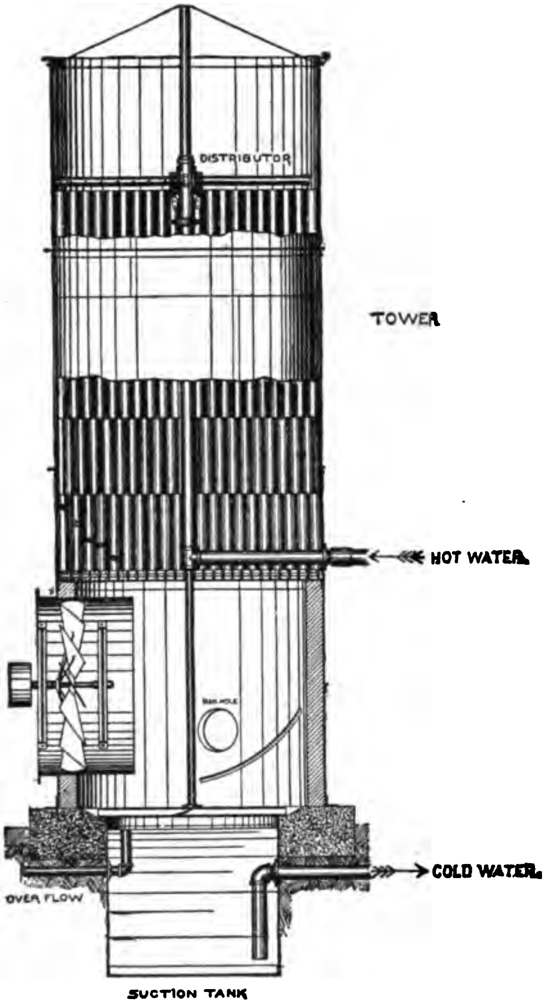


FIG. 15. Worthington Forced-Draft Cooling Tower.

number of tubes made of thin wrought iron, and arranged in sections; these sections are staggered. The water discharged from the distributer runs over these tubes and is equally distributed, giving off its heat to the metal and also to the air passing upward.

A similar cooling device to the cooling tower is the so-called open cooler. It consists usually of a wooden structure upon which a number of laths are arranged in stag-

gered rows; the water flowing from row to row is split up into thin sheets and cooled by the surrounding air. A good example of this type of open cooler, combined with a barometric condenser, is shown in Fig. 16. The condenser employed is of the dry jet counter-current type and a special air cooler is provided outside the condenser vessel. It will be noticed that after the water passes through the condenser it is pumped up to the top of the cooler, which is upon structural steel work. In order to give it sufficient

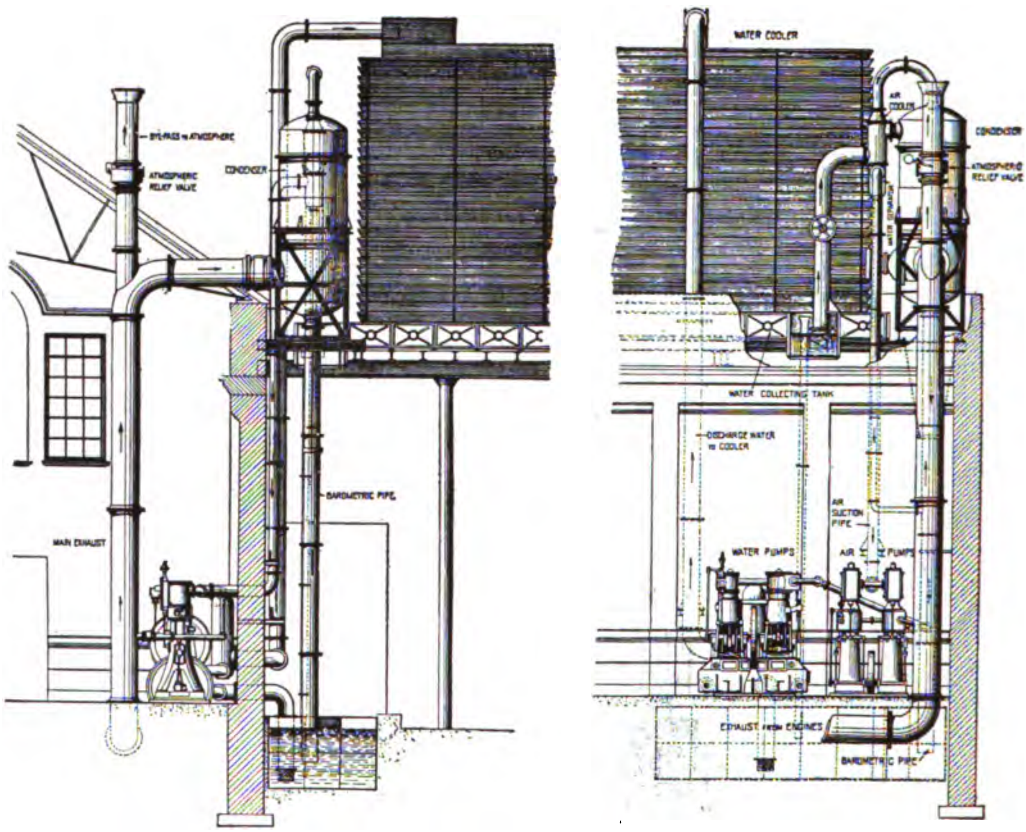
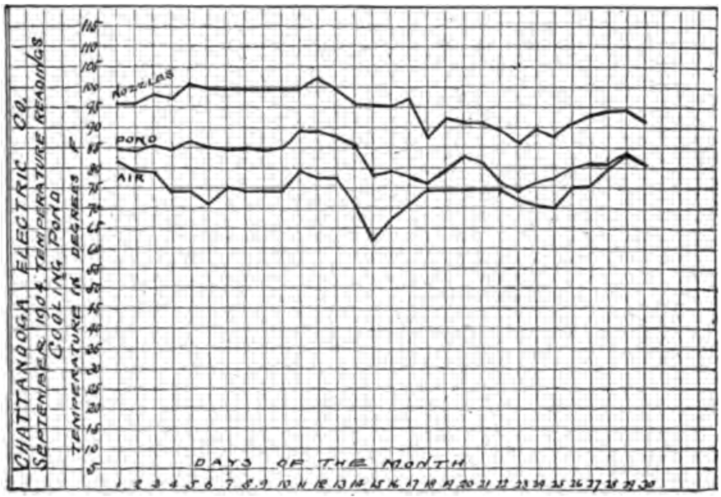


FIG. 16. Arrangement of Condenser and Open Cooling Plant as installed by the Mirrlees Watson Co., Glasgow.

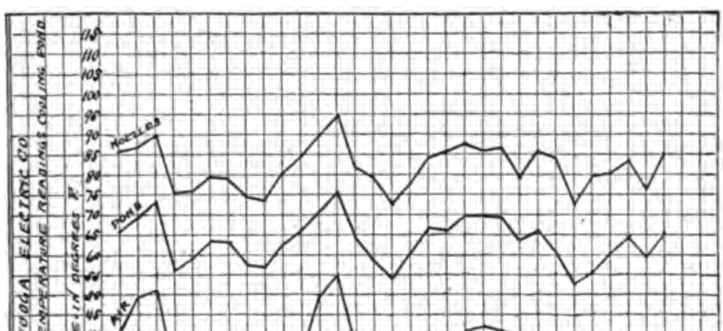
air supply they are frequently located on the roof of the buildings. The condenser itself does not require any supply pump, as the water cooler collecting tank is so close to the condenser vessel that the condensing water will siphon.

Cooling Ponds. —A simpler and cheaper method of cooling condensing water is to install cooling ponds. These ponds are nothing more than a lake, above which are arranged a series of pipes provided with spray nozzles. The water at about fifteen



Relation of Nozzle Temperature to Air and Cooling Pond, September, 1904.

Fig. 17.



Relation of Nozzle Temperature to Air and Cooling Pond, January, 1905.

Fig. 18.

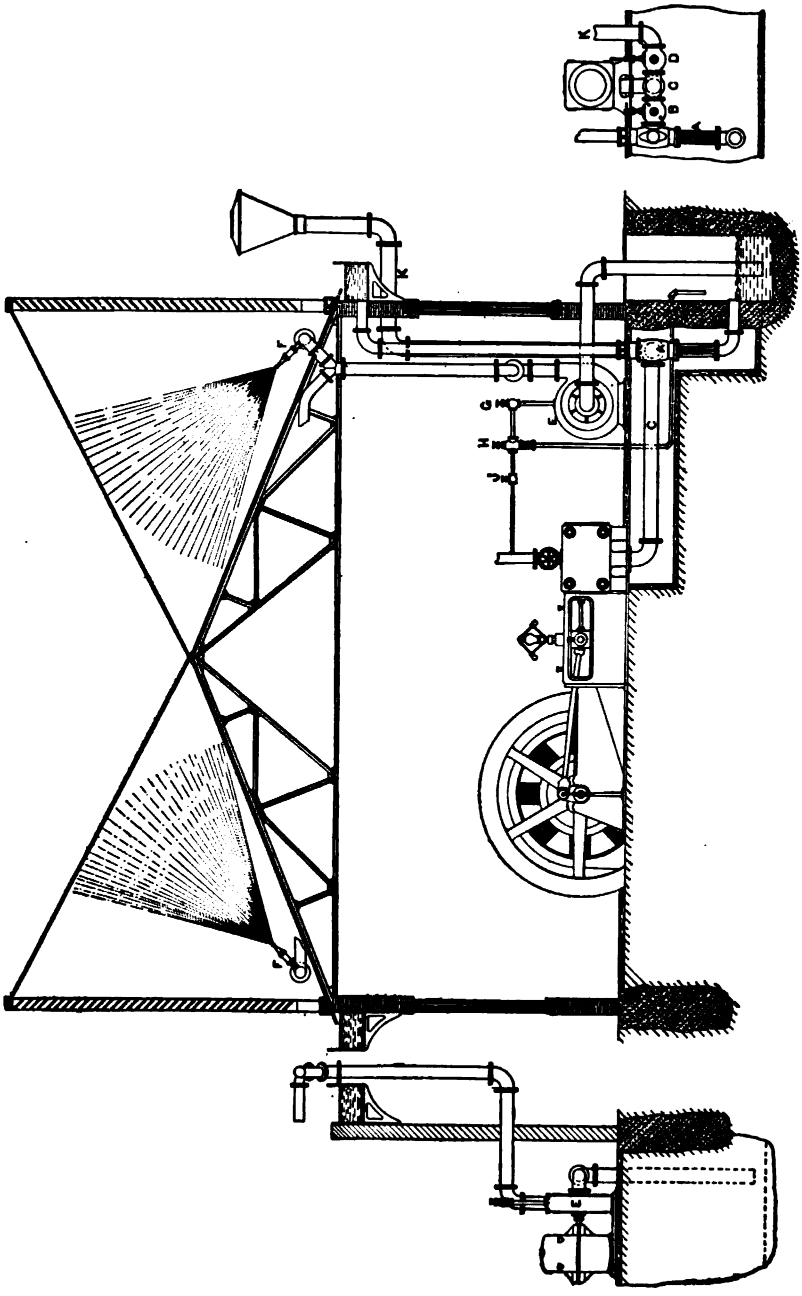


FIG. 19. Spray Cooling Plant on Roof of an Engine House.

pounds pressure issuing from the nozzle is torn into spray, and in this form projected through the air. Under favorable atmospheric conditions of humidity the water may be cooled several degrees below the atmospheric temperature, but at all times to a temperature sufficiently low for effective condensation.

These cooling ponds, like cooling towers, operate more efficiently during cold weather than during warm weather, as will be seen in the accompanying charts, Figs. 17 and 18, the readings of which have been taken from the Chattanooga Electric Company's plant, and show the difference between the temperature of a summer month and those of a winter month. During the month of September the condensing water was cooled about 12° Fahr., while in January the difference in temperature was 18° Fahr. During the time that the records, as shown on the charts, were taken, a vacuum of from 27 inches to 28 inches was maintained.

FIG. 20. Schutte and Koerting Eductor Condenser.

Usually these ponds are located on the ground, but they are occasionally placed on the roof. In the former case the water may flow by gravity, provided the condenser is located high enough to produce sufficient hydrostatic head; in the latter case, which may be chosen where ground space is limited, an additional supply pump is necessary. A scheme of this type is illustrated in Fig. 19. The system shown is of the Schutte & Koerting Company's design. The steam, after leaving the engine, is condensed in a Schutte & Koerting eductor condenser (see Fig. 20). The water is collected in a hot well trench from which it is lifted by means of a centrifugal pump to the roof, where it is discharged through the spray nozzles. The cooled water is collected at the eaves in gutters, and drains back to the water inlet of the condenser, thus completing the circuit. In order to keep the wind from blowing the finely divided particles of water upon surrounding property, a wooden fence is erected on top of the building walls, consisting of timbers and laths.

PUMPING MACHINERY.

Steam or Electric Drive.—The pumping machinery, as well as all other auxiliary machinery, may either be steam or electrically driven. If steam driven, the exhaust steam may be used for heating the feed water which under favorable conditions, and utilizing the exhaust from the exciter and blower engines, etc., may be raised to 200° Fahr. The entire amount of steam used in the auxiliaries will be from 5 per cent to

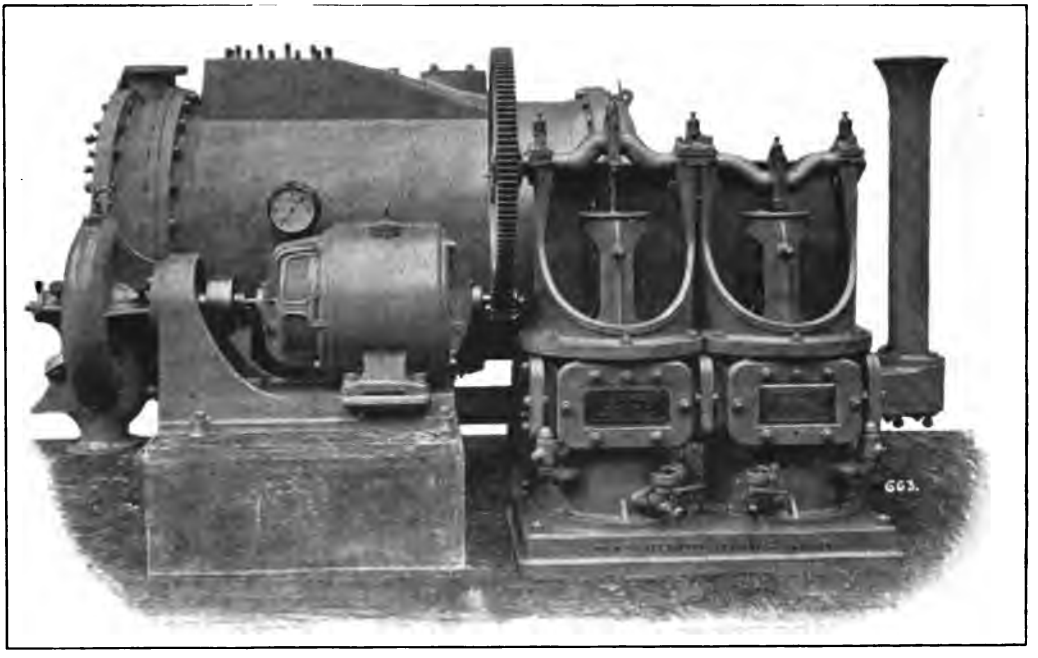


FIG. 1. Motor-Driven Surface Condenser Plant as Manufactured by the Mirrlees Watson Co., Glasgow.

10 per cent, occasionally running as high as 15 per cent of the total steam consumption, in which case it may be possible to heat the feed water to 200° Fahr.

Where, however, electrically driven pumping machinery is installed, there is no exhaust for heating the feed water, in which case the water should be heated either by economizers or live steam. It is essential to install a storage battery, so as to guard against break-down; this, anyhow, is necessary for high-voltage plants for operating the oil switches. It is also a good practice to float a storage battery on the exciter current. From the foregoing it will be seen that the installment of a storage battery is practically essential without the employment of electric-driven auxiliaries. The claim frequently made that a break-down of the main bus-bars would also stagnate the auxiliaries is not justified, for the reasons mentioned above. The installation of motor-

driven auxiliaries is neater, cleaner, easier to operate, and does not require so much floor space as steam driven. Should a break occur to the feeder to any pump, the repairs may be made in a shorter time than in case of a rupture in the steam pipe supplying a steam pump.

In favor of steam-driven auxiliaries it is said that practically the entire heat of the steam, excepting of course that which is transformed into mechanical energy and condensed in the pipes, will be sent back to the boilers in the feed water. It must, however, be remembered that all auxiliary machines are large steam consumers; a boiler feed pump will consume seventy-five pounds or even more of steam per horse-power hour, if driven by motor a horse-power hour may be obtained from the bus-bars from 10 to 15 pounds, depending of course on the make of the prime mover. As a matter of fact the question of whether to employ steam or motor-driven machinery still remains a matter of opinion. On the Continent of Europe motor-driven auxiliaries are almost exclusively used; the reverse is true in American practice. In recent installations in Great Britain many of the plants are motor driven. In order to avoid two separate steam-pipe systems, reducing valves, etc., it is of prime importance to install pumps capable of withstanding high pressure and superheated steam as used by the main engines.

Steam Consumption of Auxiliaries.—The steam necessary to operate the various pumps and auxiliary engines depends on the main engines, upon the condenser equipment, and the vacuum to be maintained. The average steam consumption per I.H.P. hour of the various pumps, both piston and plunger, may be assumed as 50 pounds. In case motor-driven machinery is used, the current being taken from the bus-bars, which are supplied by the main generator unit, where an indicated horse-power hour may be furnished by 13 pounds of steam, assuming that the efficiency of the motor, transformer, etc., is 80 per cent, the equivalent steam consumption will be 15.6 pounds. It must, however, be remembered that the exhaust from a steam-driven pump may be utilized in the feed-water heater.

The average steam consumption of the various pumps, as compared with that used in the main engine, may be considered as follows:

Circulating Pumps	1.5 per cent
Air Pumps	0.8 " "
Hot Well Pumps	0.3 " "
Boiler Feed Pumps	1.5 " "
House Pumps	0.4 " "
Oil Pumps	0.6 " "
Exciters	0.5 " "

There is other auxiliary machinery, such as is necessary for the operation of mechanical stokers, coal conveyors, etc. It may be assumed that the above figures are safe for up-to-date installations.

The Steam Turbine Committee of the Electric Light Association, 1905, on a test of the auxiliaries of a 5,000-K.W. Curtis turbine give the following figures:

	A.	B.
Output K.W.	3,410	4,758
Barometer	29.95	29.96
Vacuum	28.7	28.6
	Horse-Power.	
Circulating Pump	69.1	69.1
Air Pump	23.2	23.8
Hot Well Pump	9.2	9.8
Boiler Feed Pump	23.7	27.4
Oil Pump	5.8	5.6
Total Percentage	7.4	5.7

To compare the power required in percentage of the auxiliaries to that required by the main engines, 2.9 per cent was the amount in "A" and 2.1 per cent in "B." This percentage will decrease as the turbine reaches normal load (5,000-K.W.), and thence on will increase.

A very interesting test on the power and steam required by the auxiliary plant of a 400-K.W. Parsons turbine in the Broad Street plant of the Citizens' Light and Power Company, Johnstown, Pa., was reported by G. R. Bibbins in *Power.** The turbine discharges into a Weiss dry-jet counter-current barometric condenser. The condenser is designed to handle 24,000 pounds of steam per hour with injection water at 70° Fahr., and with a barometric reading of 30 inches capable of producing a vacuum of 27 inches. It will be seen that the condenser is very large and would take care of three turbines similar to the one tested. There are, however, only two installed at present. The chart of the test shown in Fig. 1 is self-explanatory.

Circulating Pumps. — For supplying water to the condenser, either a centrifugal or reciprocating pump may be employed. The former is more generally used, as its efficiency is much higher. The centrifugal pumps used are exclusively of the single stage type, as they are not required to pump against any very high head; they are either electrically or steam driven. They are designed either of the single or double suction type. The single suction type requires a thrust bearing which is eliminated in the double suction, owing to the fact that the water coming in on each side of the impeller equalizes the stress, therefore the efficiency of the double suction type is higher than that of the single suction.

For determining the size of the pump the most unfavorable conditions should be taken into consideration. It must also be remembered that practically all railroad

* Power required for condensing auxiliaries in a steam turbine plant. (February, 1905.)

No. of test.	Station Load. Kilowatts.	Station Load. Electrical H. P.	Station Load. Losses.	Station Load. Indicated H. P.	Efficiency of generator outlet.	Vacuum—referred to 30" barometer.	Steam. Gauge pressure	Steam. Temperature.	Steam. Superheat.	Temperatures. Hot well.	Temperatures. Cooling water.	Temperatures. Exhaust steam.	Temperatures. Air from condenser.	Pump Data. Weir reading—weir 31" wide.	Pump Data. Water per min. over weir, inc. con. steam.	Pump Data. Water per minute actually pumped.	Pump Data. Pump displacement.	Pump Data. Volumetric efficiency.	Pump Data. Total head—against pump.	Pump Data. Water H. P.	Pump Data. Mech. efficiency of air pump, belting and water pump.	Steam Consumption. Turbine. Per minute from data.	Steam Consumption. Turbine. Per kw. hour.	Steam Consumption. Turbine. Per E. H. P. hour.	Steam Consumption. Auxiliary Machinery. Per H. P. hour, from cards.	Steam Consumption. Auxiliary Machinery. Per H. P. hour—assumed.	Steam Consumption. Auxiliary Machinery. Per minute condensed.	Steam Consumption. Auxiliary Machinery. Lbs. per min. delivered to heater. 8% thermal efficiency.	Steam Consumption. Auxiliary Machinery. Lbs. per min. utilized in heater, 75% effective.	Steam Consumption. Auxiliary Machinery. Lbs. per min. chargeable to auxiliary machinery.	Lbs. cooling water per lb. steam.	% of steam required for condensation.	R. P. M. of eng. and pump.	Power. I. H. P. of steam cylinder.	Power. I. H. P. of air cylinder.	Power. To water pump.	Per cent. of total power required for auxiliaries.	Per cent of total for air cylinder.	Per cent. of total to water pump.
	Kw.	E. H. P.	H. P.	I. H. P.	%	In.	Lbs.	°F.	°F.	°F.	°F.	°F.	°F.	In.	Gal.	Gal.	Gal.	%	Ft.	H. P.	%	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	%	R.P.M.	I.H.P.	I.H.P.	I.H.P.	%	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	73	97.8	53	150.8	64.8	27.8	179	444	69	102	74.5	103	78	1.45	166	162	383	42	28.3	1.19	51.4	35.7	29.3	21.9	38	40	4.7	4.32	3.2	1.5	37.8	4.2	34.5	7.08	2.45	4.63	4.69	1.63	2.07
7	195	167.5	53	220.5	76	27.7	170	459	84	102	73	105	83	1.7	212	206	422	49	28.4	1.49	58	47.8	22.9	17.1	38.2	40	5.2	4.78	3.6	1.6	36	3.35	38	7.75	3.00	4.75	3.51	1.36	2.14
6	136	185	53	238	77.8	27.6	169	464	89	103	73.5	106.5	82.5	1.8	229	223	433	51	28.5	1.61	60.5	52.7	22.3	17	38.7	40	5.1	4.69	3.5	1.6	35.3	3.04	39	7.66	3.09	4.64	3.22	1.37	1.95
5	155	207.5	53	260.5	79.5	27.6	165	459	86	102	73.5	106.5	84	1.9	248	241	466	52	28.5	1.74	58.5	55.1	21.3	15.9	38.1	40	5.6	5.16	3.9	1.7	36.6	3.09	42	8.38	3.16	5.22	3.22	1.21	2.00
2	.	.	..	.	.	.	.	.	..	.	.	.	.	2.35	332	326	533	61	.	.	.	57	.	.	.	..	.	.	.	.	.	.	48	.	.	.	.	.	.
3	178	238	53	291	81.8	27.3	169	463	88	103	74	110	86	2.0	268	261	483	64	28.8	1.86	59.5	60.4	21.4	15.95	37.8	40	6.0	5.52	4.1	1.9	36	3.14	43.5	8.99	3.46	5.52	3.08	1.19	1.90
4	180	241	53	294	82	27.4	168	465	90	105.5	74	108	87	1.9	248	241	466	52	28.7	1.74	56.6	60.5	21.6	16.1	37.4	40	5.8	5.34	4.0	1.8	33.2	2.97	42	8.75	3.21	5.54	2.97	1.09	1.89
A	300	404	53	457	.	.	.	.	..	.	.	.	.	.	.	410	630	EST 65	28.5	2.95	EST 61	95	EST 19	14.2	.	40	8.5	7.82	5.9	2.6	36	2.74	37	12.77	4.35	8.42	2.80	.95	1.85
B	400	536	53	589	.	.	.	.	..	.	.	.	.	.	.	580	736	72	28.5	3.82	62	123	18.5	13.6	.	40	9.7	8.92	6.7	3.0	36	2.44	66	14.57	5.03	9.54	2.47	.85	1.52

FIG. 2. Test of Condenser Apparatus, Showing Efficiency of Machinery and Power used for Condensation, Citizens Light, Heat and Power Co's Plant, Johnstown, Pa.

stations are designed for a 50 per cent overload. It is more economical to install a pump large enough to carry this overload than to have one whose output is just sufficient to take care of normal load. The circulating pump is rated in gallons capacity. In order to convert this rating to horse-power, it is necessary to multiply the gallons discharged per minute by 8.33 and by the head in feet, dividing the product by 33,000. (The American gallon weighs 8.33 pounds, but the English Imperial gallon weighs 10 pounds.)

The connections between pump and condenser should be made as short and straight as possible, and also the suction line should be direct. Where no vacuum pump is installed, provision has to be made to prime the circulating pump, either by hand or by a small steam ejector or other device. When, however, a vacuum pump is used it may be started, creating a vacuum in the condenser and thence in the circulating pump. If a surface condenser is used the circulating pump may be connected by a small pipe to the suction of the air pump.

Reciprocating pumps employed as circulating water pumps may be of the single double-acting or duplex double-acting type, depending on the size and manufacture. One manufacturer may favor the single pump, another the duplex type. These pumps may also be either steam or electrically driven. In a few turbine stations the dry vacuum pump and the

centrifugal circulating pump are operated from a common shaft. A more common plan is to have one steam cylinder operate both reciprocating circulating pump and vacuum pump; with this design the pumps and condenser may be erected on one bedplate, with the condenser placed over the pumps. This arrangement has advantages and disadvantages; viz., as both pumps have to operate at the same piston speed, any increase in load on one involves an increase in speed of the other, which may not be convenient. It is the best practice to have the pumps individually driven.

Air Pumps.—Air pumps are practically all reciprocating, although there are a few rotaries on the market. The former are either of the single or duplex type, steam or motor driven. These pumps, as well as all other auxiliaries, should be of as simple and durable a design as possible.

A very efficient type of air pump is shown in Fig. 4. This type is known as the "Edwards," and is single acting, handling both air and water. This pump is possibly the most simple in design of any, requiring no suction valves and no packing on the plunger. It will be noticed that there are two pumps in this particular case which are steam driven, while in the accompanying illustration, Fig. 1, the pumps are motor driven, being connected on the same shaft as the circulating pump.

Air pumps should be so installed that all parts are readily accessible, especially if the pump is horizontal, for they all require considerable attention, if high vacuum is carried, in order to keep them in good working condition. Sufficient space should be allowed for removing pistons, care being taken that the ends of the pump will not abut against the wall.

Hot Well Pumps. — Hot well pumps are installed with surface condensers and take care of the water of condensation, either pumping same into receiving tank or into the feed-water heater. They are either centrifugal or reciprocating. Usually condensers are provided with a hot well, and the hot well pump is automatically governed by the height of the water in this well. The pump must always be located at least three to four feet below the water line, so as to have a hydrostatic head on the suction valves of the pump.

House Pumps. — The duty of the house pump is to supply water for various purposes, and its installation is of special importance where no city water is at hand. Where the water of condensation is returned to the boiler, but a certain percentage is lost by leakage, this loss must be made up by the house pump. The usual practice is to install two pumps, so that one may be held in reserve in case of emergency. If the water is used for boiler feed, wetting ashes and toilet purposes, the suction may be taken from the intake or discharge tunnel and pumped into tanks located at a height to give sufficient pressure. Where the water is also to be used for drinking purposes, a well may be driven or the suction connected to the city main.

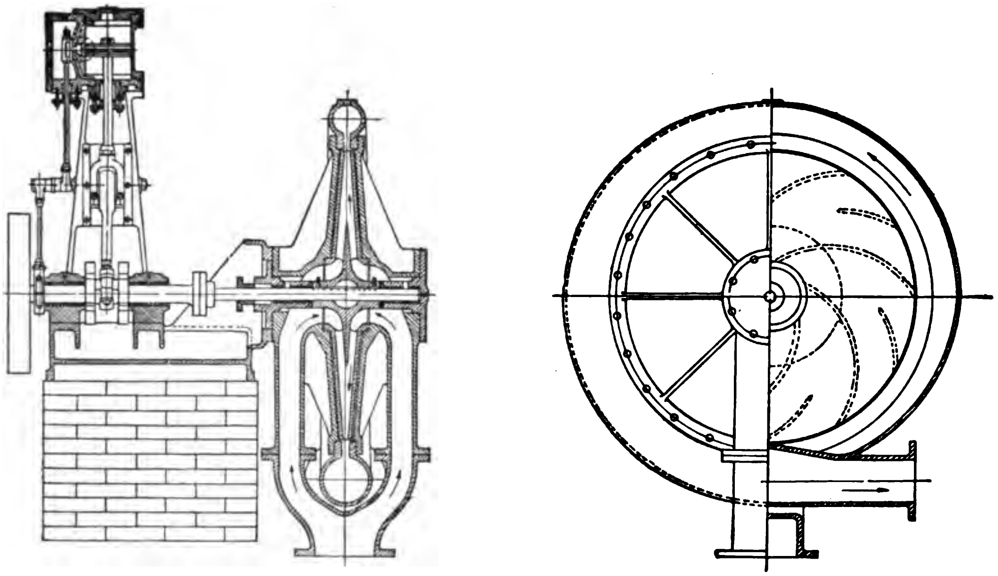


FIG. 3. Centrifugal Pump Direct Connected to Vertical Engine of the Wheeler Condenser and Engineering Co.

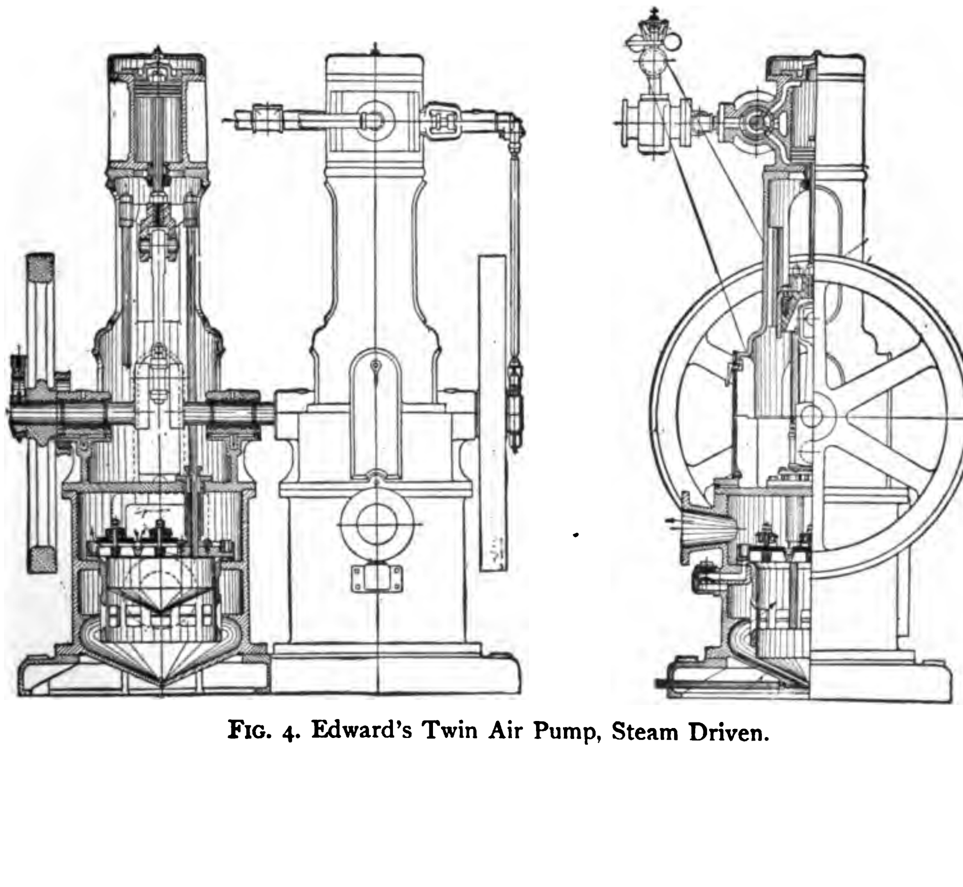


FIG. 4. Edward's Twin Air Pump, Steam Driven.

Boiler Feed Pumps. — These are generally of the outside packed plunger reciprocating type, and are in duplicate, one set being for reserve. It is good practice to install a number of small pumps rather than one large one. They should be centrally located, in order to facilitate operation, and should be equipped with pressure regulators, so that they will work automatically. The feed pumps are rated in gallons per minute

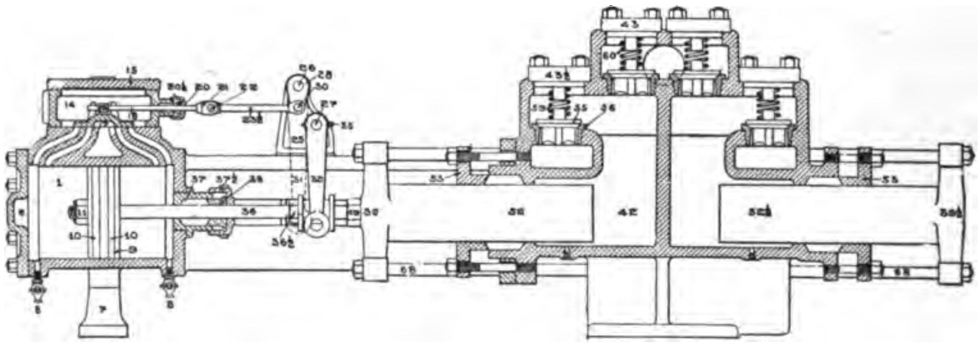


FIG. 5. Buffalo Outside End-Packed Pump.

capacity, although they are sometimes rated in America by the number of horse-power they can supply. This horse-power means boiler horse-power and is based on 40 pounds of water per hour per horse-power: this additional amount of water over the usual boiler rating of 30 pounds is to allow for slippage around plunger.

Oil Pumps. — The oil pumps may be classified as low pressure and high pressure. The former are used for a central oiling system, either pumping the oil to a storage and filtration tank, and thence by gravity to the engines, or from the filtration tank to an elevated storage tank. The high-pressure or step-bearing pumps are used with steam turbines, supplying pressure under the shaft so that the turbine shaft revolves upon a film of oil. These pumps are frequently operated by the turbine itself, but it is better practice, especially with large turbines, to have a separate pump.

Fire Pumps. — The fire pumps should be built in accordance with the rules of the Board of Fire Underwriters. These pumps are usually built for 100 pounds pressure, but it may be necessary to increase this pressure if the building is of great height. As most of the plants, especially large ones, are entirely fireproof, there are no fire pumps installed. This, of course, increases the insurance rate. Where fire pumps are installed, they must be placed in a fireproof compartment, if not in a separate building, and they also must have steam at the throttle at all times.

OILING SYSTEM.

Oil Required. — It is of vital importance to install an oiling system in all power plants, large as well as small. A complete oiling system collects the oil from the bearings, filters it and returns it to the engine, all of which is done automatically. From 50 to 70 per cent of oil used in power plants is wasted, if means are not provided to collect same as mentioned above.

The amount of oil actually consumed with a reciprocating engine is higher than that required by the turbine. It also depends to a certain extent on the workmanship and speed of engine and turbine. The Bavarian Boiler and Engine Inspection Society made a thorough investigation of the subject of oil consumption, and they found that in compound and triple expansion engines of from 100 to 1,500 horse-power the approximate oil consumption per horse-power hour amounted to two grams, while in a Parsons steam turbine of the same capacity the approximate oil consumption amounted to two-tenths gram per horse-power. However, these figures mean the oil that will be actually consumed by evaporation, etc.; a greater amount of oil is, of course, required for flushing these bearings; for instance, it is claimed that in the Chelsea plant for eight 5,000-K.W. turbines, 33 gallons of oil are required per minute.

Filtering Tanks. — The filtering tank should be so located that the oil will flow to it by gravity. The tanks should be installed in a separate building or a fireproof compartment. This compartment may also contain the oil pumps as well as the waste cleaner and drier. Provision to guard against fire is necessary in the design of the oil room. The door should be so arranged that it will shut automatically. If the room is a large one, it is better to install two doors, one large and one small, the latter one as a means of easy escape for the attendant. As these rooms are usually installed in the basement, it is of importance to protect the structural steel with brick or concrete. The floor should be provided with proper drainage, as it is necessary frequently to clean the tanks and filters.

Many of the larger power plants have filtering tanks of special design, but common practice is to install some regularly manufactured article. The tanks should be in duplicate, or so arranged in compartments that one compartment may be cleaned at a time, without putting the entire tank out of service. Large tanks may be constructed of many compartments; the oil, entering through cheese cloth or light canvas filters, passes through the compartments at a low velocity, precipitating any foreign substances. The filtering

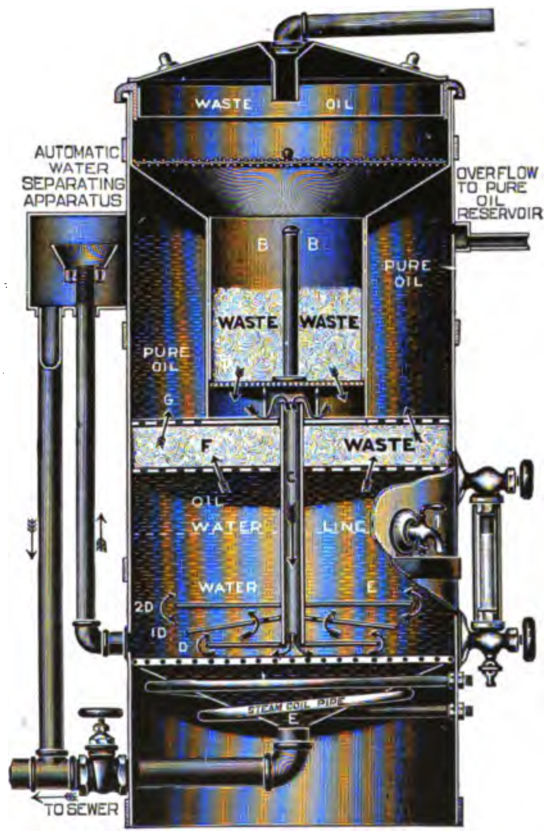


FIG. 1. Burt Oil Filter.

tanks may have a steam coil to heat the oil, thereby increasing the speed of filtration and causing more rapid precipitation. When, however, high-speed engines or turbines are used, and the temperature of the oil returned to the filters is high, the use of the steam coil may be dispensed with.

Very frequently the oil returned from the engine contains a certain amount of water; it is necessary to abstract this water with the filter. Fig. 1 shows a typical oil filter of this type as manufactured by the Burt Manufacturing Company. The oil entering at the top passes through the waste contained in the center chamber, from where it passes downward through the pipe "C," is heated by the steam coil and flows upward through the water contained in the lower portion of the tank. This water forces the oil through the waste "F" into the pure oil compartment, from which it is drawn off and re-used. The water is discharged to the sewer through the automatic water separator, shown on the left-hand side of the cut.

Another very efficient oil filter is shown in Fig. 2, representing the Turner system frequently used in connection with the Curtis turbine. As will be seen this tank is

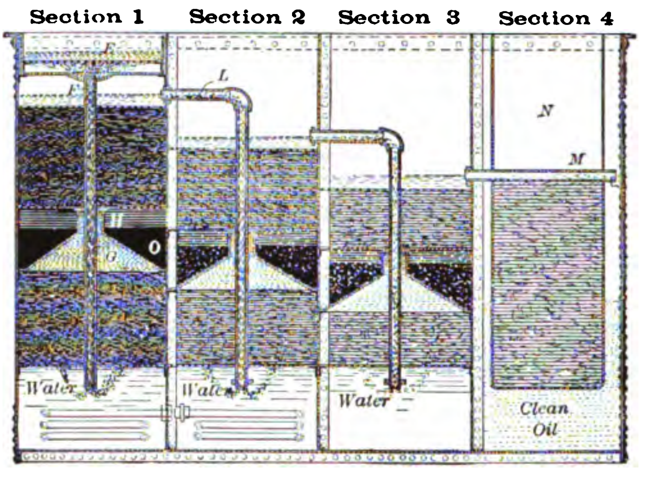


FIG. 2. Turner Oil Filter.

divided up into four sections, the oil passes through the filtering material of each section, having its temperature raised by steam coils in the first two sections.

A very efficient oil filtering tank is shown in Fig. 3. Similar tanks have been installed in the 59th and 74th Street power houses, New York, but of a much larger capacity than the one represented in this cut. These filtering tanks, of which both plants possess two, have each a capacity of 6,500 gallons per hour.

The tank is divided into chambers by partition walls, extending alternately to the top and bottom of the tank, giving the oil an up and down flow, thus increasing precipitation, which will be greater the lower the velocity. The oil before entering the tank passes through canton flannel bags, arranged in trays as shown in the illustra-

tion. These bags are removable and when dirty may be replaced by clean ones. The pipe connections are such that any chamber may be separately cleaned without shutting the entire filter down.

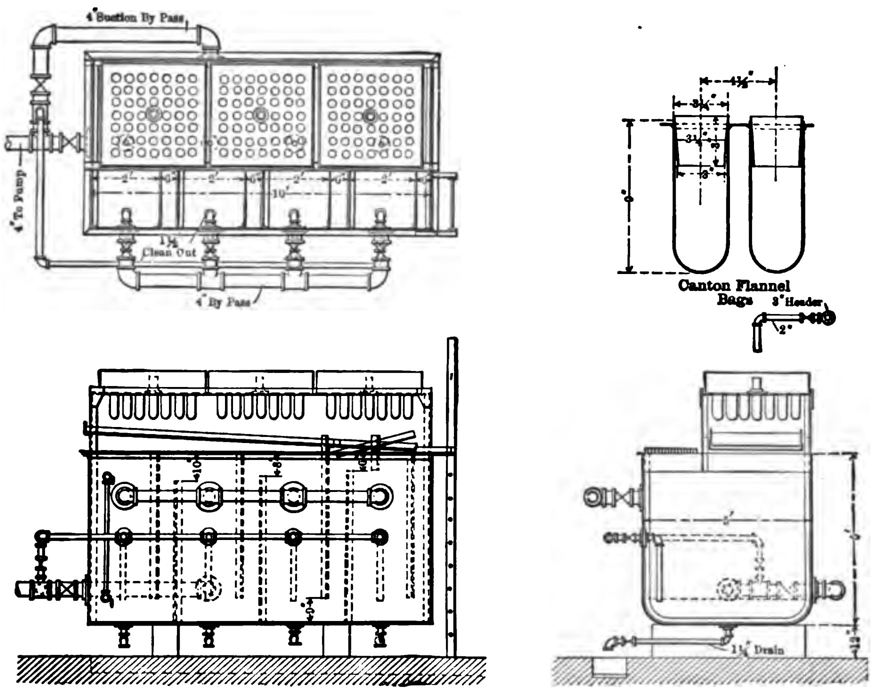


FIG. 3. Layout of an Oil Filter Tank System, similar to which some are installed at the 59th St. and 74th St. Plants, New York. (*Power.*)

Oil Pumps. — The pumps required for an oiling system are either high pressure or low pressure. The latter are used with a central oiling system. Duplicate pumps should be installed, in order to keep one in reserve.

With the steam turbine high-pressure pumps are required to pump the oil to the step bearing, or beneath the shaft of horizontal turbines. Some types of turbines have these pumps set on the turbine frame and operated by the turbine shaft, while with other types individual pumps are used. This is especially necessary where a number of large size turbines are installed. It is better practice to install several small size pumps than one or two large ones, as the possibility of shut-down is thereby lessened.

With the vertical Curtis turbine in some instances water is used for the step bearing with practically the same results as those obtained with the use of oil. The entire equipment, with the exception of the filtering tanks, is the same as the oiling system.

Supply Tanks. — Frequently it is necessary to install one or two elevated supply tanks, from where the oil is fed by gravity to the various bearings. These tanks must be properly vented, and where more than one tank is employed they must be inter-

connected. In order to avoid complicated and long pipe mains, these tanks are preferably placed somewhere in the center of the plant.

As the oil is used over and over again, and its temperature is increased each time it is used (especially with turbines and high-speed engines), it is usually necessary to cool the oil by means of water cooling coils placed in the supply tank.

Oil Piping.—The return pipes leading the oil from the various bearings or collecting pans to the filtering tank may be of either wrought or cast iron; the former is preferable, however, for small pipes. If wrought iron is employed screw fittings may be used. In order to secure a good gravity flow for the oil the pipes should be pitched at least one inch in every ten feet. Where many returns are connected to one common header, provision has to be made for the removal of air. This is accomplished by placing ½-inch or ¾-inch vent pipes on the header. These vents must extend above the highest point in the return piping, so that if the pipe discharging to the filter should be plugged the oil will not escape through the vents. To facilitate cleaning the pipe, it is good practice to install crosses instead of tees in the header, one leg being plugged.

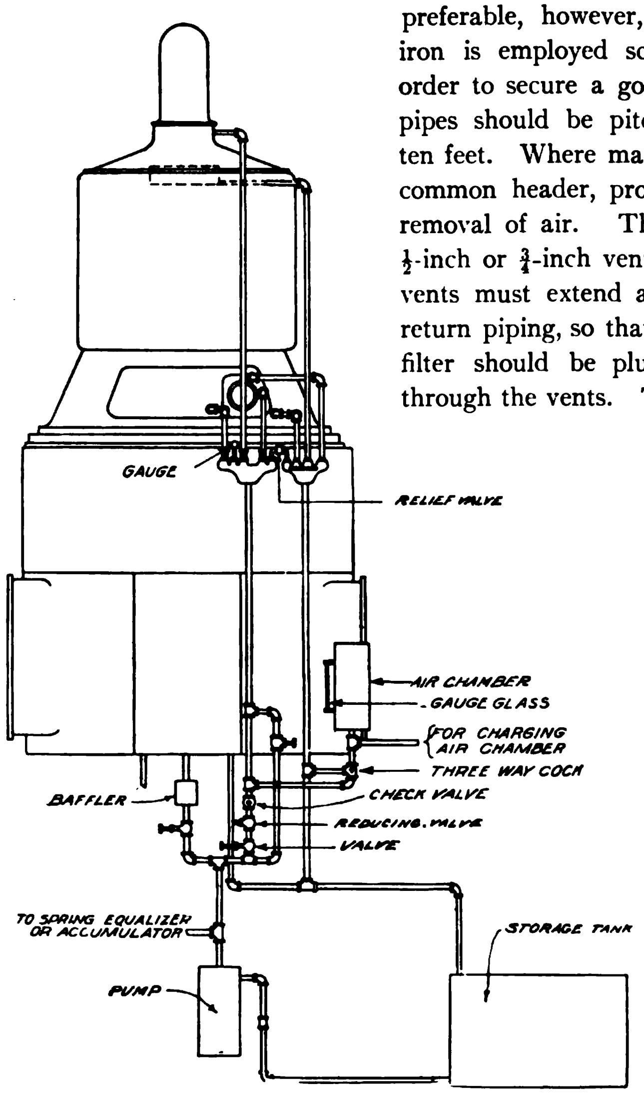


FIG. 4. Piping for Oiling System of Curtis Turbine.

The supply pipes from the filter to the elevated tank and also the pipe from the tank to the engines should be made of brass or copper. This is absolutely necessary, as steel, wrought-iron or cast-iron pipe contains a scale which oil loosens, and if this scale gets into the bearings it is liable to cause considerable damage. Galvanized iron pipe has been tried for supply piping, but experience has shown that the galvanizing will wear off and the pipe will scale as badly as a black iron pipe.

All supply pipes in plants employing reciprocating engines are low pressure, while those where turbines are used are high pressure. All return pipes are low pressure. The pressure employed in

high-pressure systems varies with the size of turbines installed; for instance, with 5,000-K.W. Curtis turbine the pressure used would be about 800 pounds per square inch; it varies also with the types of turbine employed.

It is essential to keep the pressure of oil constant. This may be accomplished by weight accumulators, or a tank with an air pressure above the oil. The weight accumulators are unsightly and occupy a great deal of space, while the tank is small and gives just as good results, is less expensive, and may be placed in an inconspicuous corner.

Automatic throttle valves must be placed in the steam connection to the pump, and properly piped with the air tank or weight accumulators. Some types of turbines require that bafflers be installed in the pipe line near the bearings. These bafflers are so arranged that they take up any shock which may result from the stroke of the pump.

The distributing pipes on the turbine are usually supplied by the manufacturers. The plant designer's duty is to connect these to the oil mains, tanks and pumps.

CHAPTER VII.

ELECTRICAL EQUIPMENT.

Introductory. — The development of the electrical features of power plants, especially the design of switchboards, has become so specialized in recent years that the mechanical engineer, the power plant designer, has less and less to do with this department. Owing to this fact he is becoming less familiar with this part of the work and, as with modern power plants and increased transmission distances and potentials, the electrical equipment is constantly requiring changes and improvements, a knowledge of this subject is becoming more difficult of attainment and simultaneously of more importance. As reliability of service and economy of operation are both of prime importance, it is necessary that the mechanical and electrical engineers work in perfect harmony. The following discussion of the electrical equipment is for the purpose of supplying the information required by the mechanical engineer for the proper performance of his work, rather than for the complete design of the electrical outfit; however, it must be remembered that a large part of the mechanical design is affected by the electrical features and *vice versa.*

Similar to the mechanical equipment of the plant, the electrical apparatus should be divided up into the unit system, *e.g.*, each generator and exciter should have its own panel on the switchboard. This simplifies the operation of the entire plant.

Generators. — The electrical characteristics of the generator, voltage, etc., must be decided upon by the electrical engineer and depend upon the transmission system. While, of course, the capacity of the units depends largely upon the load diagram, which is usually plotted by the electrical engineer, it also depends upon the various characteristics and economies of the prime movers, and must, therefore, be considered by the mechanical engineer.

If reciprocating engines are used, the generators are mounted directly upon the main shaft and care must be exercised by the mechanical engineer to have sufficient space around the generator and in the pit to give easy access to all parts for repairs, etc. Railings must be installed to guard against accidents. Anchor bolts for the generator frame should be similar to those used for the engines, in order to secure uniformity.

Where turbines are employed little attention to the generators is required from the mechanical engineer, as they are carried on the turbine bedplate itself, while in case of certain turbines, as the vertical Curtis, where galleries are necessary, care should be

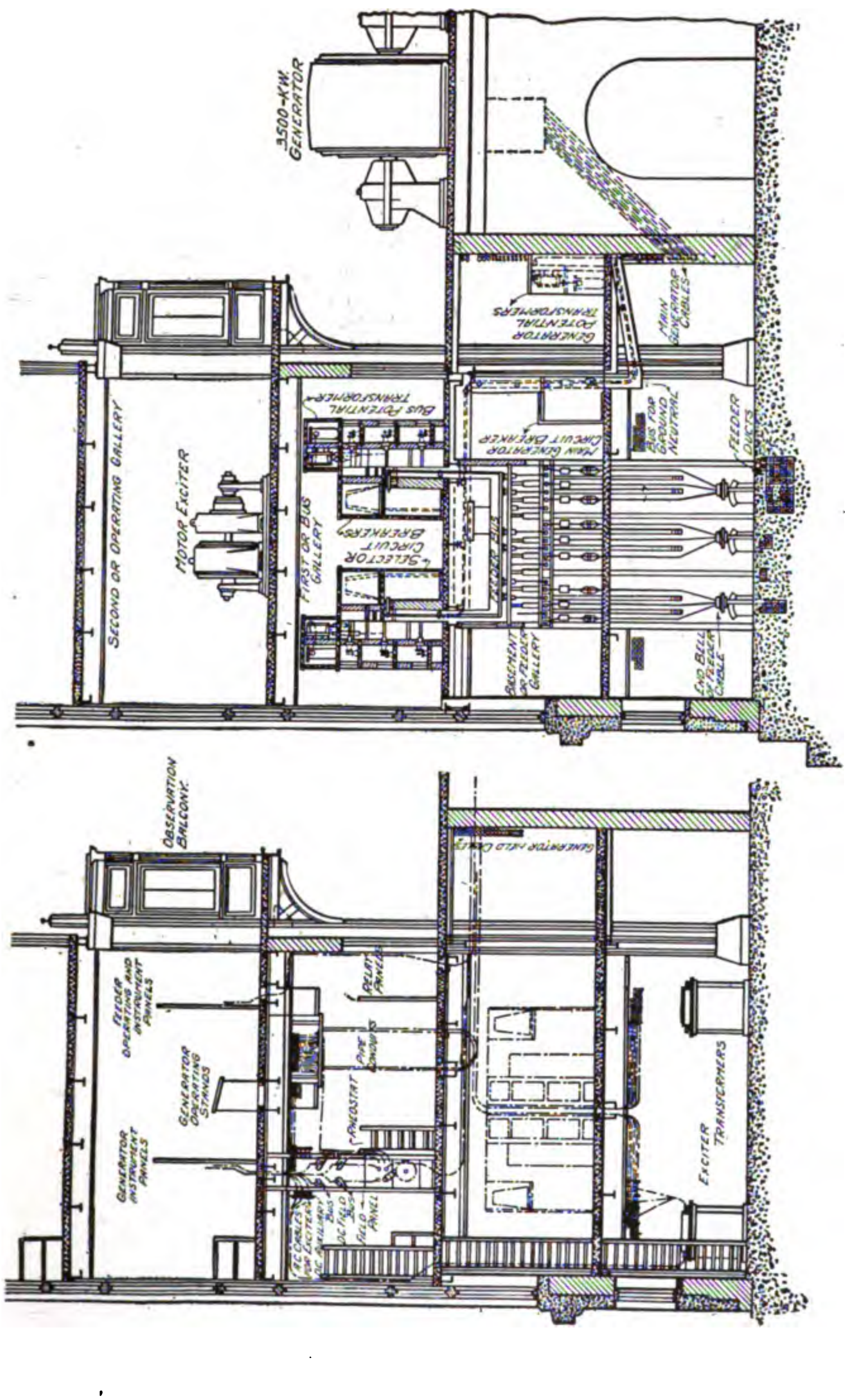


FIG. 1. Sections through Switch Galleries, Long Island City Plant.

exercised to have these galleries similarly located and designed with the other galleries required in the power plant. This is of especial importance where access from one gallery to another is necessary. A notable instance of these conditions is that of the plant of the Delaware & Hudson Company at Mechanicville, N.Y. (at present under construction), where galleries of the Curtis turbines are directly connected with the

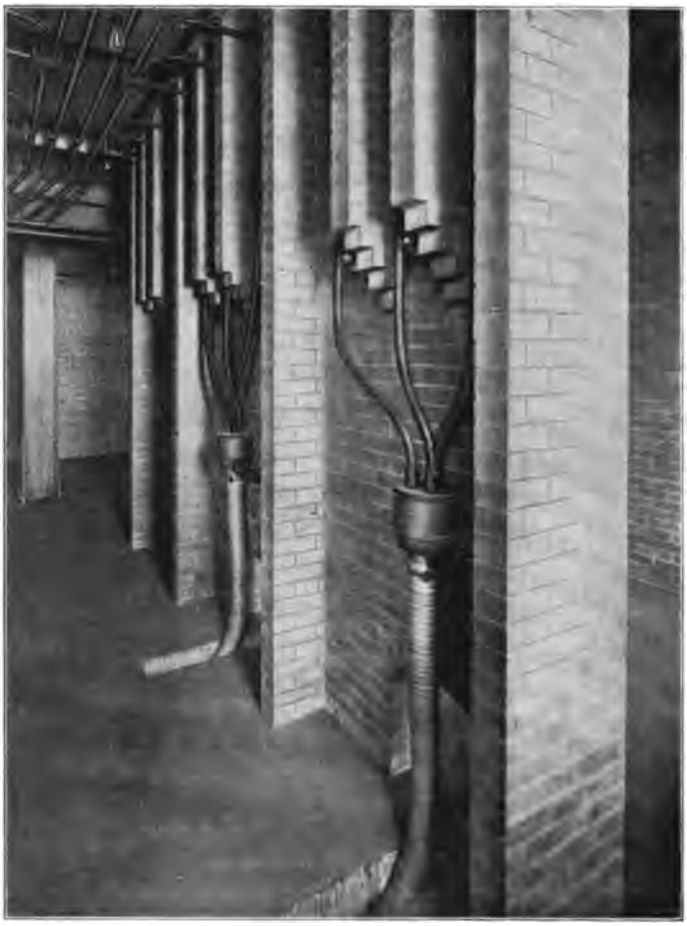
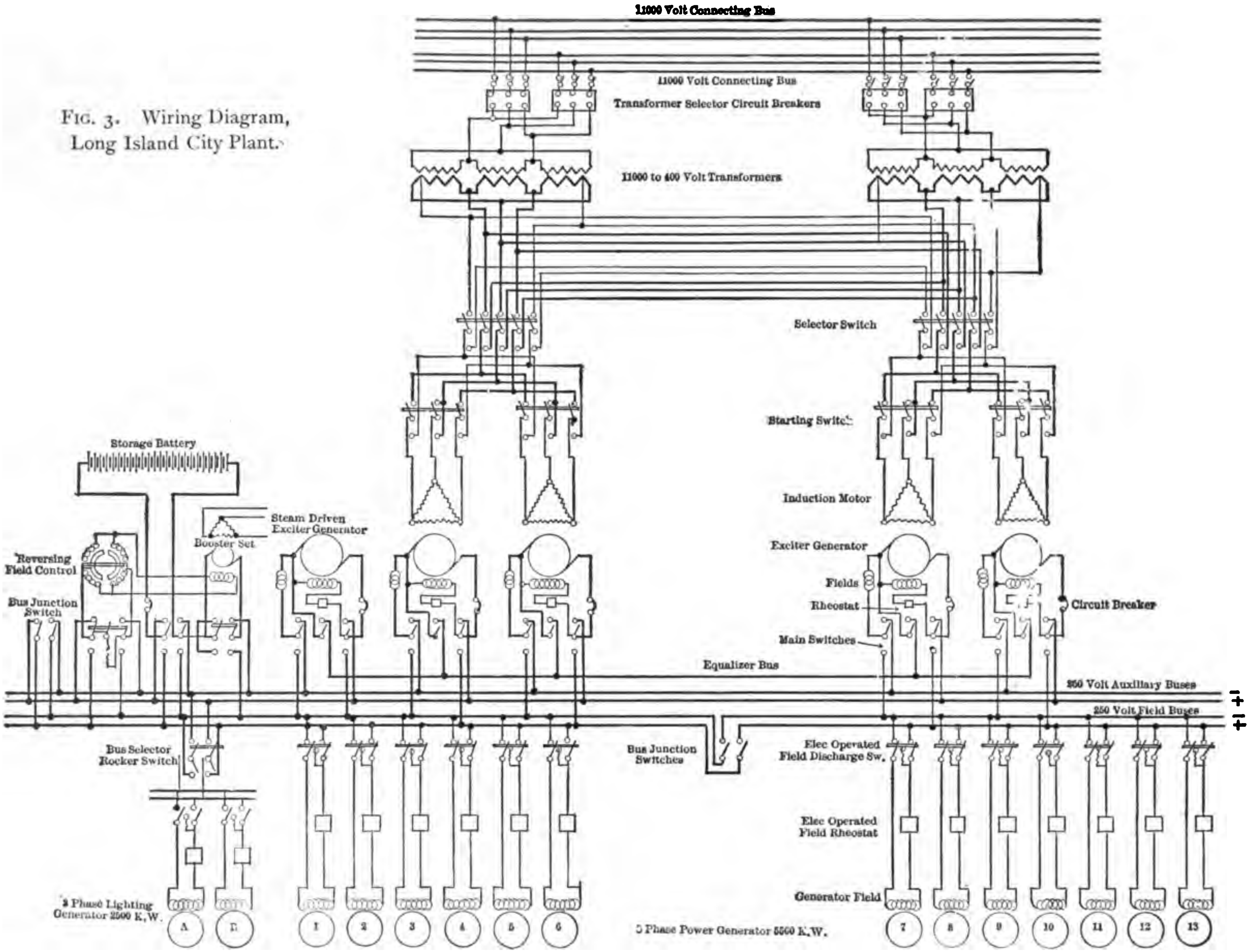


FIG. 2. High-Tension Feeder Cables, in Basement, entering Conduits, Long Island City Plant.

switchboard galleries, thus enabling the switchboard attendants to take care of the generators, which require little attention, making a material reduction in the operating force.

With certain types of turbo-generators, for instance, the Westinghouse-Parsons, air ducts have to be provided for cooling purposes, owing to the fact that the generators are of the closed type, thus preventing natural ventilation. These air ducts, which are built of very light material, may be carried through or near a basement window, so as to give a supply of fresh air. They must be provided with a fine wire screen, so as to keep out foreign material.

FIG. 3. Wiring Diagram, Long Island City Plant.



Exciters. — The exciters may be either steam or motor driven, or a combination of both. With the Parsons turbine the exciter is sometimes mounted directly upon the turbine shaft, as will be noticed in the article on turbines. Without question, the motor-driven exciter is more economical, as, for instance, a non-condensing high-speed engine or turbine may easily consume from 40 to 50 pounds steam per I.H.P. hour, while when current is drawn from the main bus-bar system, which in turn receives its power from the main generator unit, the steam consumption is from 12 to 14 pounds per I.H.P. hour. It must be remembered that the efficiency of a motor generator is approximately 80 per cent, which would give an equivalent steam consumption of from 13 to 15 pounds per I.H.P. hour. With motor-driven exciters it is important to install a storage battery. Since in practically all high-tension plants, a storage battery is required to operate oil switches, etc., it might as well be increased so as to have sufficient capacity to float on the exciting bus-bars, thus giving a more uniform excitation and at the same time taking care of peak loads.

Another practice is to install a combined motor and steam-driven exciter outfit, in which case the steam-driven exciter will start up the plant while the motor-driven exciters are used under ordinary circumstances. With this system, of course, a storage battery is not so essential.

Careful attention must be given to the choosing of the proper size of exciters, since while these are small items in the first cost of the total plant, they are of prime importance for the reliability of operation. Frequently the error is made of installing only a single exciter unit of capacity sufficient to handle the whole plant. This is decidedly poor engineering, as at least one (depending upon size of plant) exciter should always be kept in reserve. Where, however, the conditions are such as to make it undesirable to install double the exciter capacity required, the unit should be divided, so that in case of emergency the entire plant would not lie idle.

The size of the exciters depends upon the character of the plant, varying from ½ to 2 per cent of the total generator output (including reserve unit). For instance, a 20,000 K.W. plant, normal capacity, should have two 100 K.W. exciters.

Generator Leads. — All leads between generators, exciters and the bus-bars should be carried in the basement, where there is one, or in clay ducts or iron pipe imbedded in the concrete of the floor. In the latter case, manholes must be provided at suitable places to give ready access for pulling in the cable. It is desirable to avoid unnecessary bends and run as straight to the switchboard as possible. Where galleries are used, as with the Curtis turbines, the generator leads may run under the gallery in iron pipes.

Switching Room. — Before the dimensions of the plant are determined, the space required for the switching rooms should be thoroughly studied in connection with a competent electrical engineer, for too frequently mistakes are made in designing this part of the plant too small, resulting in unnecessary crowding of apparatus. One, two or three floors may be provided, depending upon the system adopted, and it is the

duty of the electrical engineer to decide how much room he requires for the high-tension bus-bars, oil switches and the various switchboards, etc. The switching room may be located either at one end of the plant or running at the side and occupying the entire length of the generating room, and it should be separated from the latter by a partition wall, either of fireproof material or glass, in order to keep all dirt away from high-tension apparatus. The latter is preferable where, owing to the general arrangement, no light can be thrown into the switching room. It must here be remembered that all outside windows in the switching room must be kept securely closed, so as to prevent any foreign material, rain, etc., from blowing in and causing serious grounds or short circuits. It is also important to keep all roof leaders, etc., away from the switching apparatus, as leakage or dripping due to condensation may cause serious damage. In some notable instances entirely separate buildings are used for switching purposes. (Port Morris station, New York, and Fisk Street plant, Chicago.)

The accompanying illustration, Fig. 4, represents the switching compartments of the new "Waterside" station of the New York Edison Company, while Fig. 5 shows a section through the switching compartment of the 59th Street plant, New York. Both stations are of recent design and may serve as good examples of modern American practice. An example of British practice is shown in Figs.

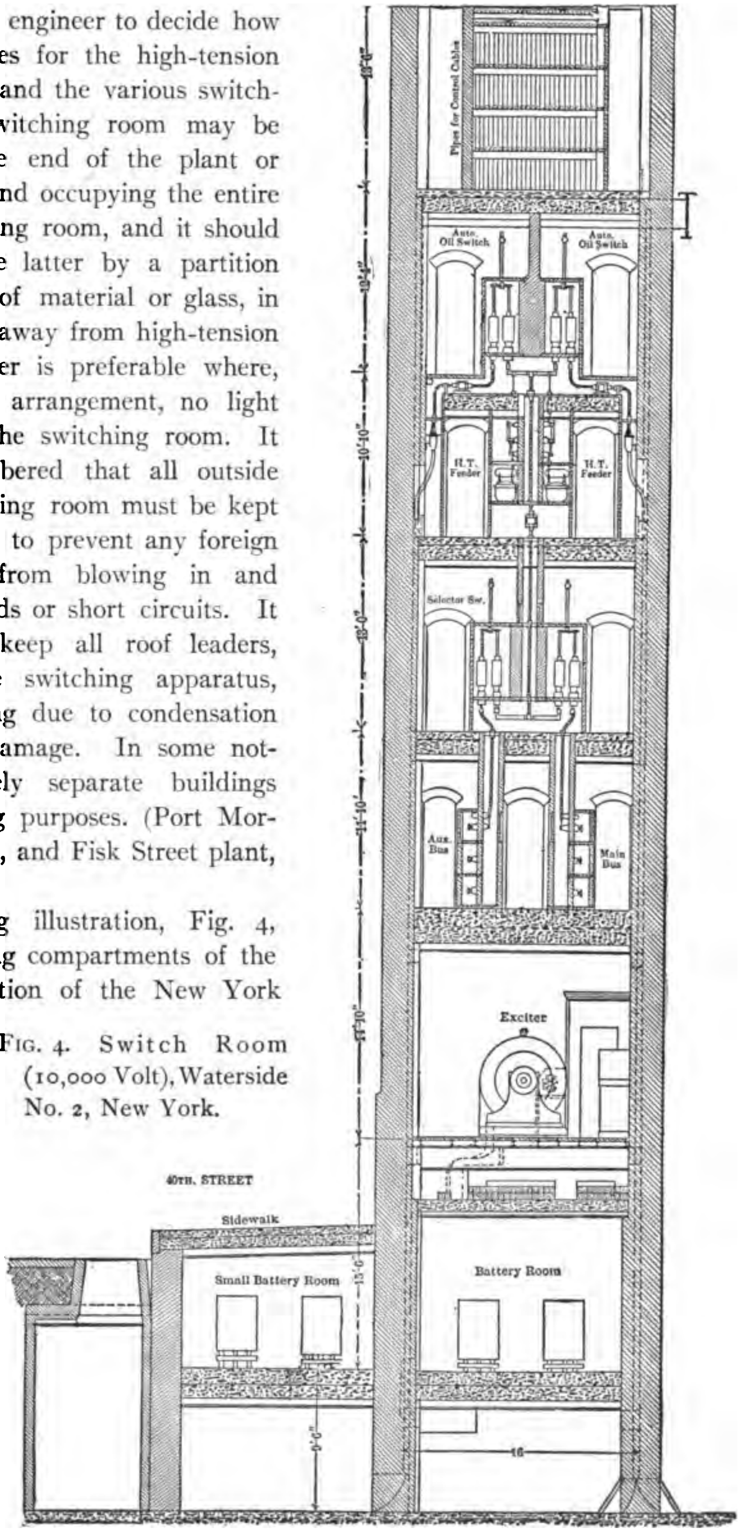


FIG. 4. Switch Room (10,000 Volt), Waterside No. 2, New York.

6 and 6a, which was presented before the Institution of Electrical Engineers, London, by Messrs. Merz and McLellan, in a paper on the design of power plants.

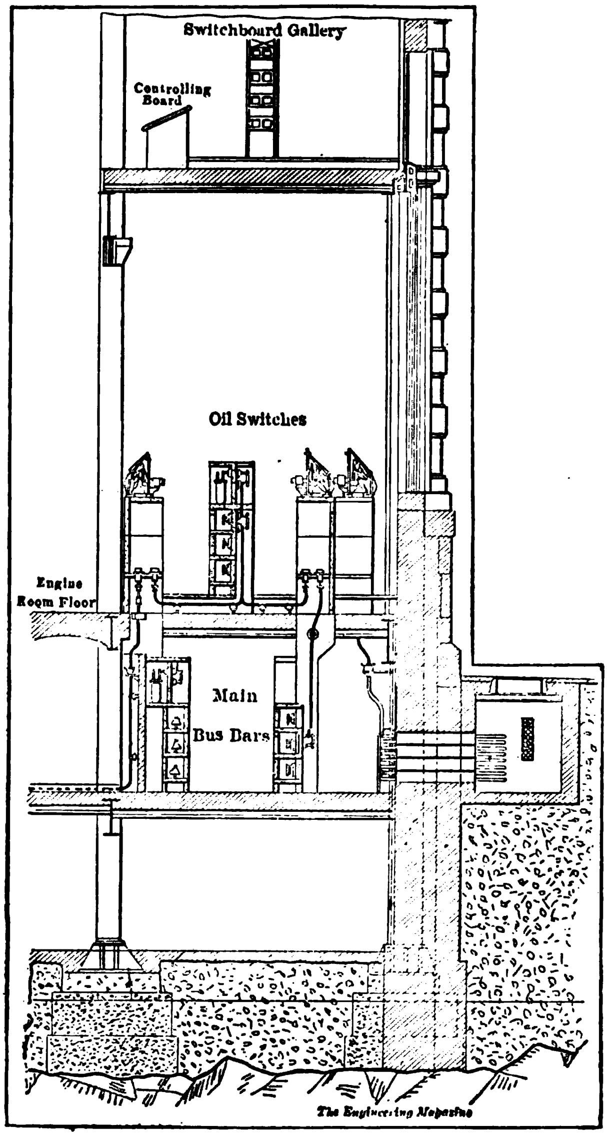
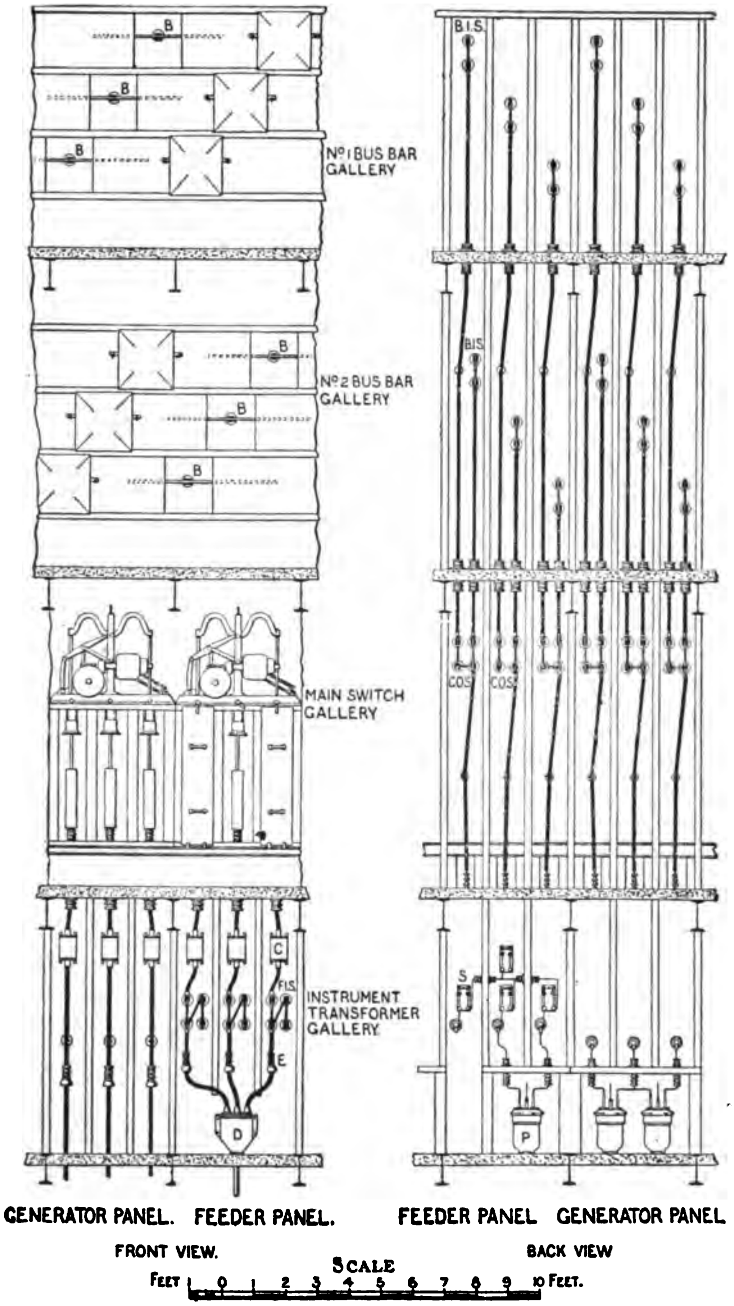


FIG. 5. Cross-Section through Switch Room, 59th St. Plant, New York.

The main controlling board should be installed in the gallery above the bus-bars and oil switches, so that the operator may easily overlook the entire generating room. This might be done by having large openings in the partition wall, between the gen-

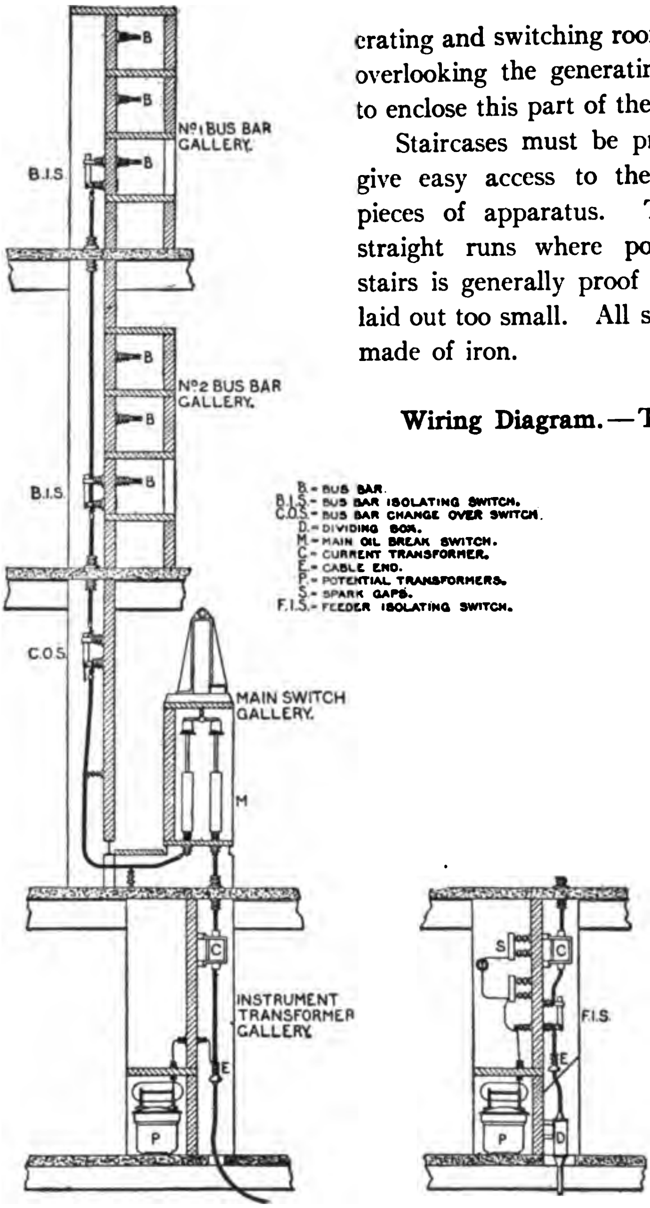


BACK AND FRONT VIEW OF H.T. SWITCH GEAR.
CARVILLE POWER STATION

FIG. 6.

erating and switching rooms, or by installing a balcony overlooking the generating room. It is good practice to enclose this part of the switching room in glass.

Staircases must be provided between the floors to give easy access to the various compartments and pieces of apparatus. These should always be in straight runs where possible. The use of spiral stairs is generally proof that the switching room was laid out too small. All staircases, of course, should be made of iron.



CROSS SECTION OF HIGH TENSION SWITCH GEAR.
CARVILLE POWER STATION.

FIG. 6a.

Wiring Diagram.—The wiring system in the electrical part of the plant corresponds exactly with the piping in the steam part. It should be made as simple and at the same time as flexible as possible. The wiring diagram should be so laid out as to avoid as much as possible any interruption to the service, and the apparatus should be arranged so that in case of accident the disabled section may be easily cut out. For this purpose sectionalizing switches must be installed, and in order to make repairs on these switches, disconnecting switches must be placed on each side.

The bus-bars are arranged in the "single," "double" or "ring system." Where a plant serves for both light and power it is advisable to install two bus-bar systems, keeping the two services separate, and double-throw switches so arranged as to use any generator for light or power. These bus-bars

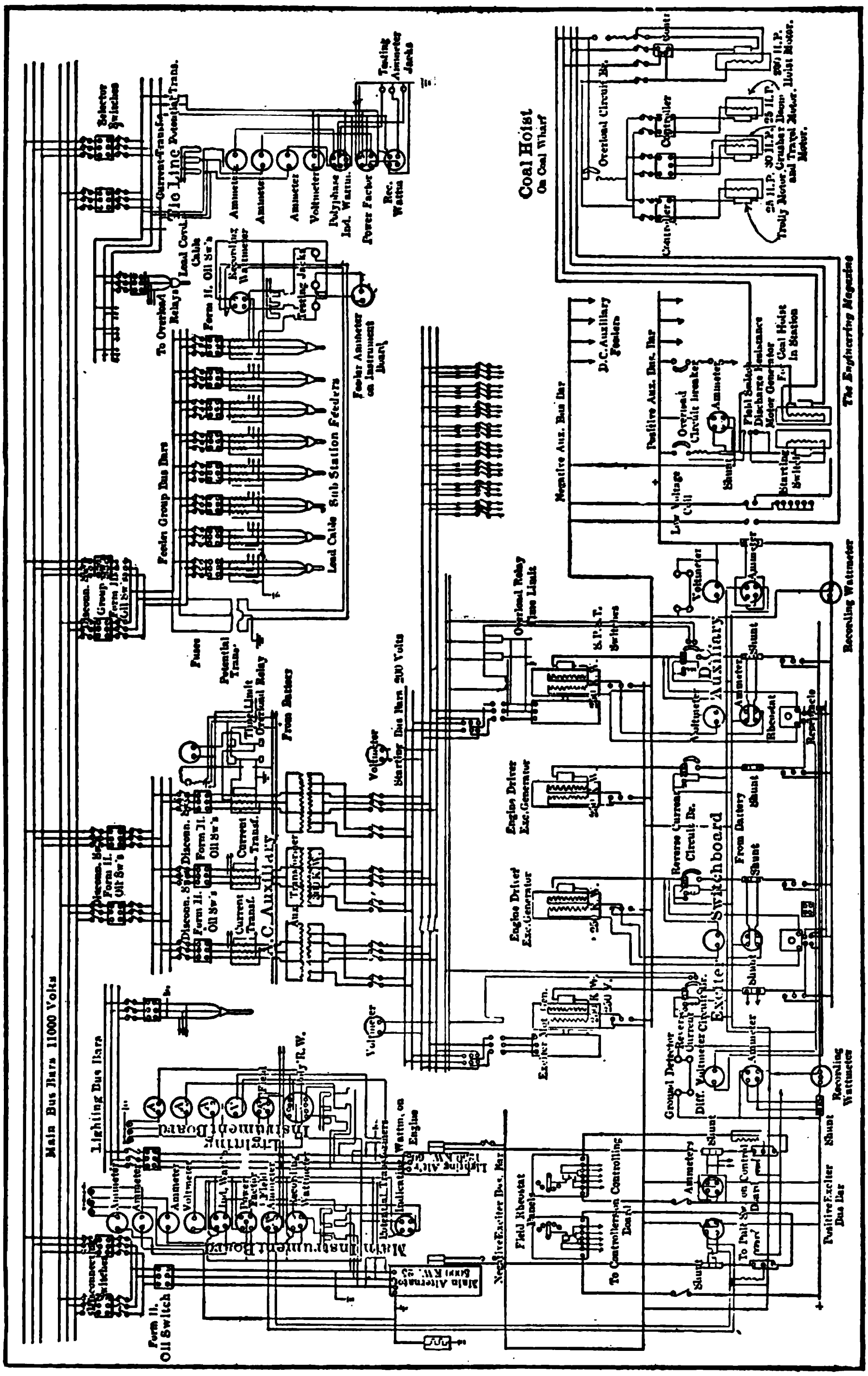


FIG. 7. General Wiring System, 59th St. Plant, New York.

are frequently distinguished as main and auxiliary bus-bars. The same may also be applied to the outgoing feeder systems.

It is not the intention to give a description of the wiring diagram of the complete equipment, but Fig. 7 shows the wiring diagram of the complete plant of the 59th Street

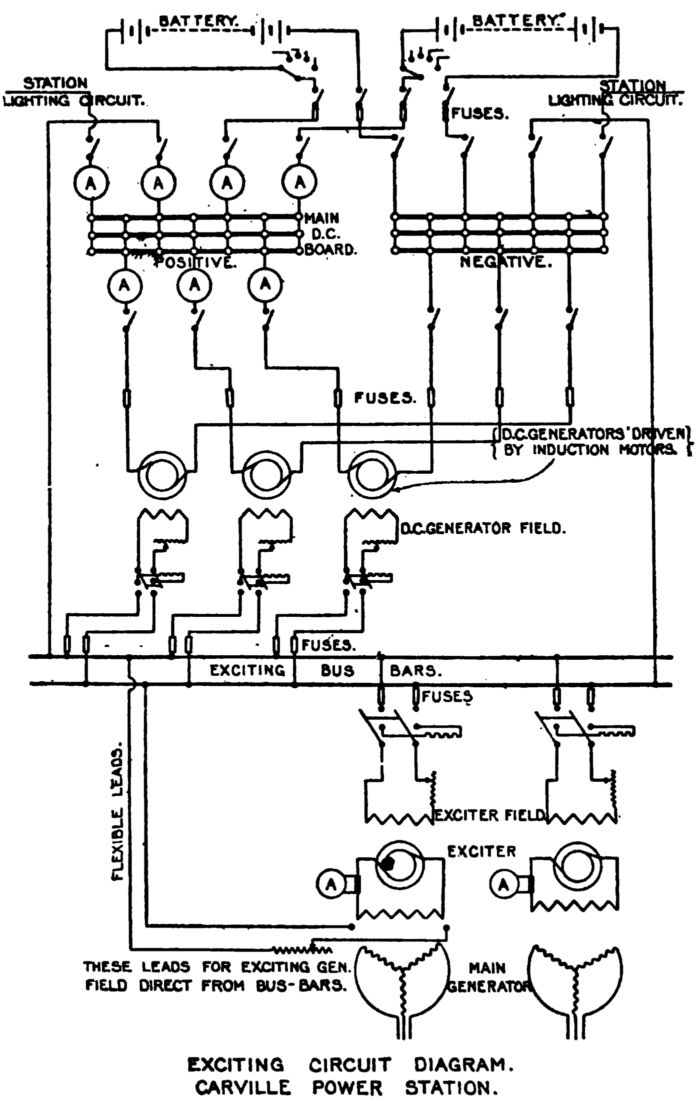


FIG. 8.

power house, New York. By studying this cut it will be seen that the connections of the machinery for the entire power plant are included, while in Fig. 8 only the exciter wiring of the Carville power station is shown. Other wiring diagrams are given in Chapters X and XI on various power plants.

Bus-Bar Chambers. — Bus-bar chambers should be made fireproof, either of reinforced concrete or brick. All compartments should be so laid out as to give easy access to any piece of apparatus.

The floors for carrying the bus-bars and oil switch chambers must be calculated according to the weights to be carried, depending, of course, upon the arrangement and the voltage and power employed. Four hundred pounds per square foot is usually chosen for a system of 11,000 volts.

Oil Switches. — Oil switches are used where high tension is employed and are either motor, solonoid or hand operated. The first is most favorable for high voltage. The

FIG. 9. Oil Switches and Bus-Bar Compartments, 59th St. Plant, New York.

oil chambers containing the switches are set in compartments made of concrete or brick, similar to those used for the bus-bars. On top of these cells are mounted the motors, which are operated from a centrally located controlling board. These switch cells should be so located as to give easy access to all parts of the switch and switch mechanism, and the oil chambers so arranged as to be easily removable without disturbing the mechanism of the switch. The switch cells should be provided with a removable door made of wired glass, slate, or asbestos lumber held in a wooden frame, so that the oil chamber may be easily removed. Fig. 9 shows the coil switches and bus-bar compartments of the 59th Street power plant, New York. As this photograph

FIG. 10. 6000-Volt Bus-Bar Room. Modern Swiss Practice (see also Figs. 11, 12 and 13).

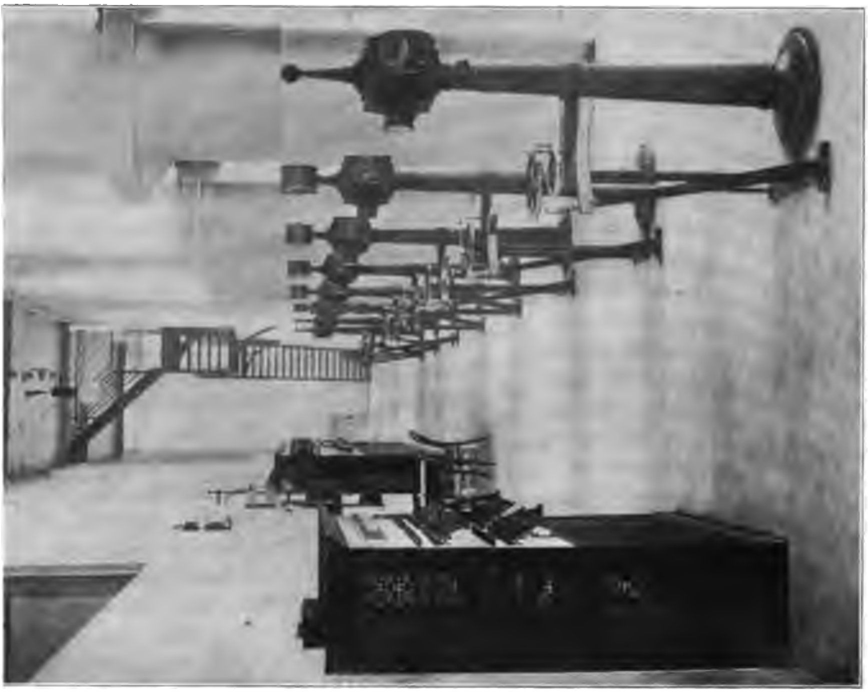


FIG. 11. Columns and the Switchboard Gallery, Each Equipped with Complete Set of Generator Apparatus.

Designed and Installed by the Oerlikon Maschinenfabrik, Oerlikon, Switzerland.

FIG. 12. 27,000-Volt Oil Switch.

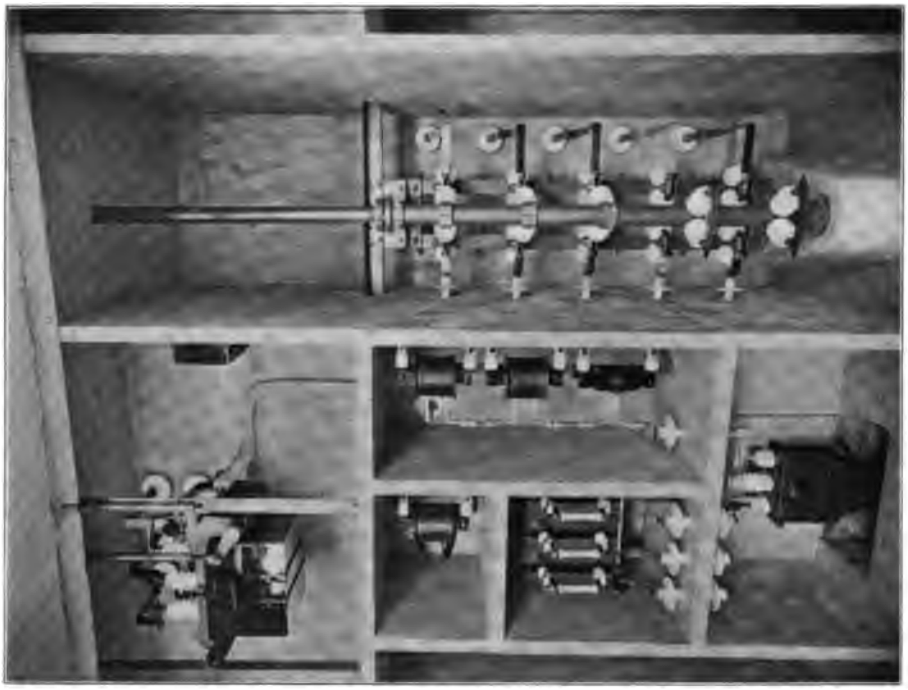


FIG. 13. Apparatus for a 6000-Volt Generator.

Reinforced Concrete Compartments without Covers, Installed at the "Obermatt" Plant, Luzerne, Switzerland (see also Figs. 10 and 11).

was taken during course of erection, the system of arrangement and method of construction are more clearly shown.

Continental practice is to operate these oil switches even with very high voltages by hand and a system of levers, as will be seen in Fig. 10, showing a 6,000-volt bus-bar room of the Obermatt station of Lucerne. As will be noticed, they are operated from the floor above. Attention is also called to the fact that the bus-bars are not placed in separate compartments, as is customary in America and Great Britan. This practice, of course, can be adopted only where plenty of space is available. It will be noticed, however, that the two bus systems are separated by a shelf.

This station, which was designed and installed by the Oerlikon Company, Zürich, Switzerland, is one of the latest and most modern illustrations of recent European practice, especially in regard to the electrical equipment, and, therefore, additional

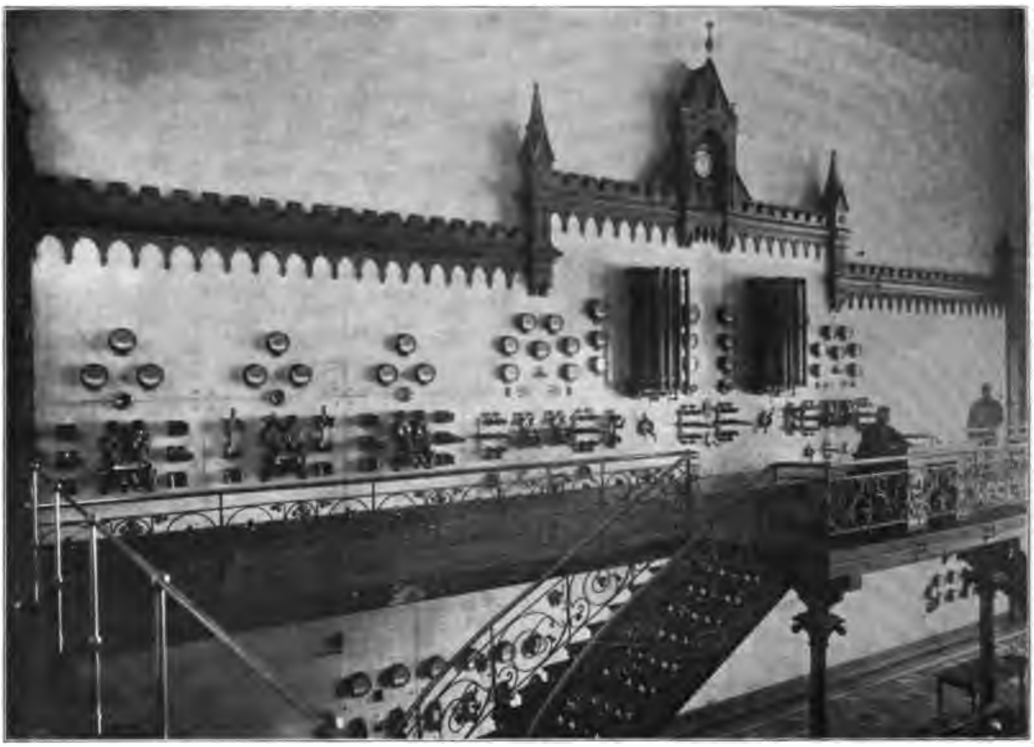


Fig. 14. Architectural Features of a Low-Tension Switchboard at "Bille" Plant, Hamburg. (Siemens Schuckert Co.).

cuts will prove of interest. The system is designed for multiple voltage service. Each piece of apparatus is mounted in a separate compartment, no covers, however, being provided.

Switchboard. — The main switchboard and controlling boards should be centrally located in order to facilitate operation. From here all high-tension switches are con-

trolled by low-tension current devices. The switchboard itself is usually made of enameled slate or marble on a structural steel or pipe frame, without any further ornamental decoration. A different practice is in vogue on the Continent of Europe, where the boards are made of white marble mounted on frames of very elaborate design. Two examples of this practice are illustrated in Figs. 14 and 15, the former representing a switchboard at a power plant in Hamburg, Germany, designed by the Schuckert Company of Nuremberg. It will be noticed that this is a low-tension switchboard, the slabs of white marble being framed with an elaborate ornamental wooden molding. Of course it must be remembered that this board was built before high-tension alternating current came into universal use, and forced the adoption of iron frames, as seen in Fig. 15, representing the ornamental features of modern design. A notable departure from this practice is that common in Switzerland

Fig. 15. Type of Modern German Switchboard at Siegen.
(Siemens Schuckert Co.)

and recently also used in other countries, namely, of mounting the instruments and controlling levers on a so-called instrument post. One of these posts is usually provided for each generator and exciter, an example of which is given in one of the accompanying illustrations (Fig. 11). The great advantage of this feature is that, during operation, the attendant faces the generator room, instead of turning his back, as is

necessary in the ordinary practice. For controlling the outgoing feeders, switchboards are installed. If current is used for both light and power, the bus-bars as well as the controlling panels should be kept separate. The entire switchboard should be self-explanatory, and in order to facilitate operation, especially for new hands, a diagram of the wiring system should be mounted in a convenient place. Care must be taken to have all parts of the system thoroughly protected by automatic devices.

Storage Battery. —The capacity of the storage battery depends entirely upon its purpose, as has been previously stated. It may be installed only for operating the high-tension switches and assisting the auxiliary machinery, or for lighting the station in case of emergency.

Storage batteries are desirable for maintaining a constant voltage on the exciter bus-bars, which is of especial importance where motor-driven exciters are run direct from the main bus-bars. The fluctuation of the generator voltage will affect the excitation current, thus aggravating the former. Besides this a storage battery floating on the exciter buses may easily take care of peak loads. In case of break-down of the exciter units, either motor or steam driven, the storage battery will give excellent service.

It must, however, be remembered that the first cost and maintenance of a storage battery is high, and the depreciation is approximately 10 per cent per annum.

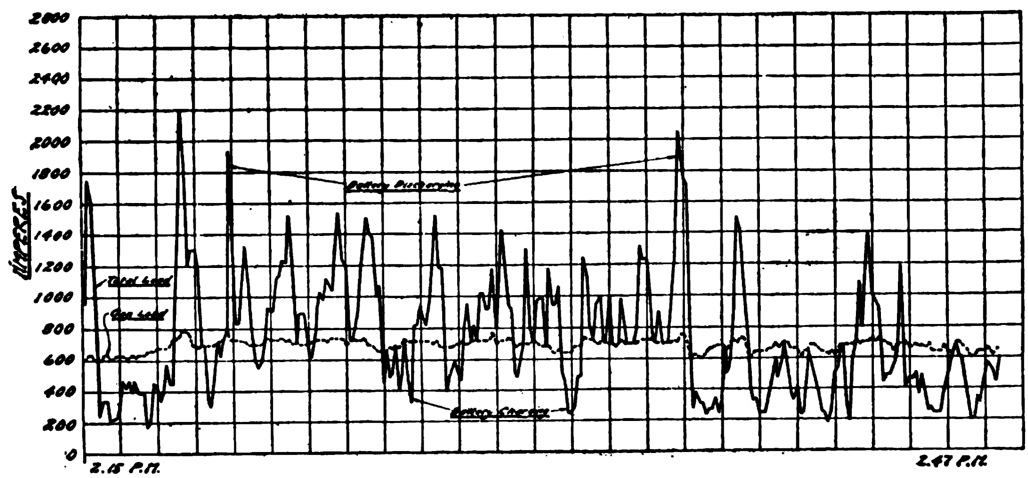


FIG. 16. Load Diagram on Plant of the San Francisco, Oakland and San José Ry. Co.

Fig. 16 shows the load diagram of the power plant of the San Francisco, Oakland & San José Railway Company, clearly illustrating the effect of a storage battery on railway power service. It will be noticed that the minimum current is about 200 amperes, while the maximum is about 2,200. The division of the load between the battery and the generators is also shown in the chart, the fluctuation of some 2,000 amperes being taken care of by the battery. Although there are not now many

engineers who advocate direct current for long-distance transmission for railroading or lighting the storage battery still holds a very prominent place in sub-stations, and there are many instances where storage batteries are used in the main power plants. In railway practice the battery is always installed with a constant-current booster, so adjusted that the load on the generator is uniform and the peaks are taken on the battery.

In order thoroughly to ventilate the battery room, fans are usually installed. These fans are best operated by motors, as it is difficult to bring steam pipes across the generator room to the switching room.

CHAPTER VIII.

THE DESIGN OF SMALL POWER PLANTS.*

Introductory. — Notwithstanding the fact that the majority of central stations are below 3,000 K.W. capacity, those usually discussed are of larger capacity. This may be due not only to the prominence of the plant and the exceptionally large size of prime movers, but also to the fact that they supply, either directly or indirectly, the needs of a large number of people. The record-breaking advertising of the various manufacturers is also a potent factor in increasing the interest in these larger plants, since of course the larger the plant the more notoriety gained by the company supplying the machinery, as well as by the designer of such a plant. Such power plants are, however, as above stated, only a very small percentage of the total number of plants. The design of these plants in many respects is an entirely different proposition from that of the large central station, since what may be a small item in the latter may prove to be a large percentage of the total first cost of the small plant. Not only from a financial point of view is it a different proposition, but also in the technical design. Inasmuch as the break-down of a single unit in a small plant constitutes the disability of so much larger percentage of the complete equipment, so much more important is the necessity for break-down units in the former. As, however, a small station cannot be equipped with as large a number of emergency units as are frequently found in larger plants, it becomes of vital importance to select the proper size of the main machinery, such as boilers, prime movers, etc. It is, therefore, the author's intention to discuss briefly the various questions encountered in the design of a small power plant.

There are many items affecting the decision in regard to the requisite capacity of the plant as well as the individual prime movers, such as urban and interurban railway service, municipal and private lighting, character and amount of power load for industrial and domestic purposes, possible forms of contract, etc. There is not space here to discuss more fully this preliminary although very important special subject, as the above factors vary so widely with the character of the town; and, therefore, assuming that these points have been settled, we will confine ourselves to the detail of designing.

Assuming the plant to be for supplying light and power to a given community scattered over a considerable area, the current generated in the power plant will be 2,300 volts, sixty-cycle, three-phase alternating, being stepped down at sub-stations. On account of the character of the load curve we will assume that it has been decided

* See author's original article, *Electrical Review*, April 20, 27, May 4, 1907.

to install a plant of 2,250 rated horse-power or 1,500 K.W. This plant shall consist of three 750-K.W. units, one of which will be always in reserve, while the building itself will be large enough to accommodate a fourth unit of equal or greater capacity in order to meet the increasing demand after the first few years. The plant will be run condensing.

As these prime movers are so designed as to operate under an over-load of 50 per cent, the maximum combined capacity of the two prime movers will therefore be

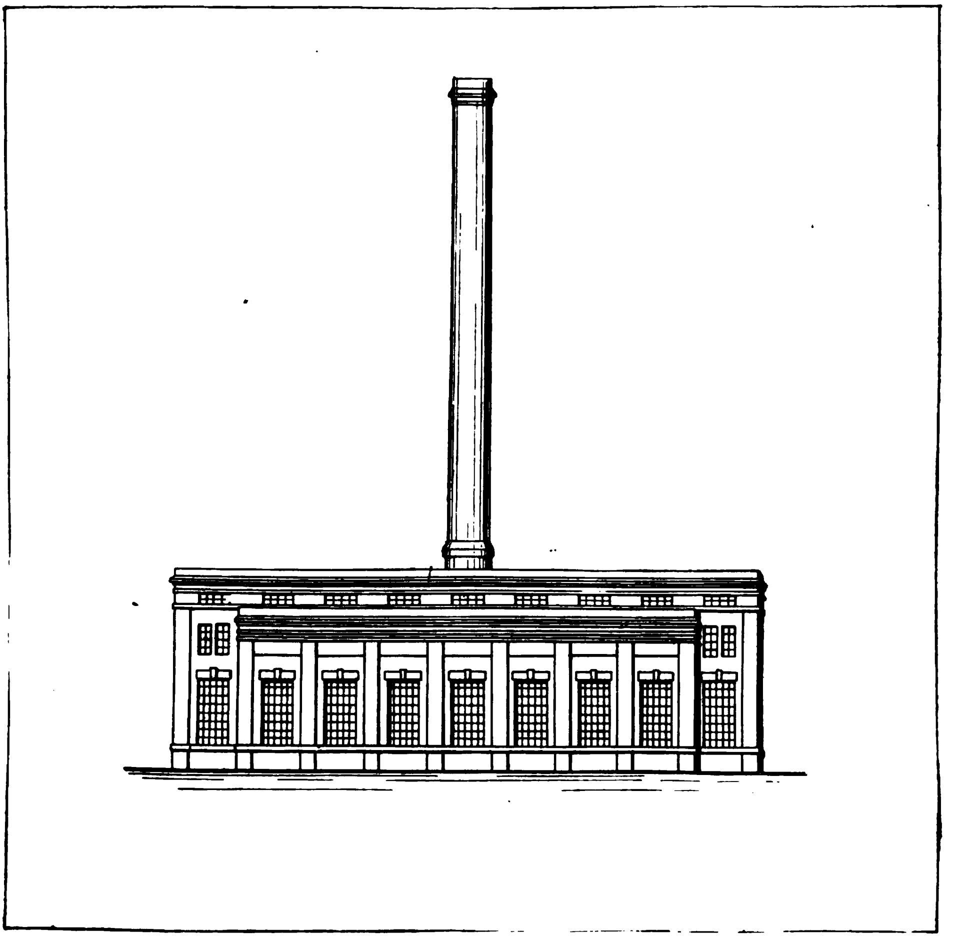


FIG 1. Superstructure (*Electrical Review*).

2,250 K.W. In order to choose the proper size of boilers it is necessary to know the steam consumption of the prime movers and the auxiliaries, assuming that the latter are steam driven. Practice has proven that the auxiliaries consume (including leakage, drip, etc.) from five to ten per cent of the total steam consumption, although there are plants where this runs up as high as 15 per cent, and some notable instances in recent prominent turbine plants where this is lower than 5 per cent.

Assuming further that the plant is located in a remote district where skilled labor is scarce, the water consumption will be materially increased on account of the waste incident to too frequent blowing off of boilers, draining of main steam pipes of the main prime movers and auxiliaries, etc. Under such conditions the liberal consumption of 20 pounds per K.W. hour (including auxiliaries, etc.) is assumed. This results in a total water consumption of $1,500 \times 20 = 30,000$ pounds per hour. Assuming that water-tube boilers have been selected and that 3 pounds of water will be evaporated per square foot of heating surface, boilers with 10,000 square feet of heating surface would be required. This, however, assumes normal conditions for the boilers, (with an overload of 50 per cent on the turbines); an overload of approximately 35 per cent being good practice for maximum economical forcing of boilers. Making allowance for this overload, approximately 11,000 square feet of heating surface is required. As it is American practice to rate boilers in horse-power and 10 square feet of heating surface in a water-tube boiler is equivalent to one "boiler horse-power," 1,100 horse-power would be required, this giving a ratio of 0.73 boiler horse-power per K.W.

Type and Size of Plant. — At least two boilers should be installed for each prime mover, which would necessitate four 275-horse-power boilers (2,750 square feet). As, however, the boilers require frequent cleaning and repairing and as there is one spare prime mover, the same spare capacity of boilers should be installed. Of course, space must also be left for two more boilers to supply the future prime mover when installed. As will be seen in the accompanying plan, Fig. 2, the boiler house runs parallel to the generating house, the boilers being arranged in one row, in batteries of two. The chimney is located between the fourth and fifth boilers, thus giving a symmetrical layout. Allowing 5 feet clearance between two adjacent batteries and 5 feet between the batteries and the end walls, with 23 feet between boilers Nos. 4 and 5, which space is occupied by the chimney, boiler-feed pumps, feed-water heater, etc., and assuming that a battery of two 275-horse-power boilers has a width of 24 feet, the total length of the boiler house would be 143 feet. The width of the boiler house should be 50 feet, thus allowing ample clearance for withdrawing of tubes, etc.

On account of the present popularity of turbines we will adopt them for this plant. As turbines occupy a comparatively small floor space, the length given for the boiler plant is more than necessary for the turbine room, and as will be seen from the plan, 113 feet is all that is required. Taking into consideration the removal of the condenser tubes and the dissembling of the turbines on the generating-room floor, the width of the turbine room will also be 50 feet. About 10 feet of the generating room is set apart for switching purposes, offices, toilets and lockers, etc., thus giving a building covering 12,800 square feet, which gives 4.28 square feet per K.W. normal rating. This figure is of course liberal, as this is a country power plant and it is not good practice to crowd the plants as is done in cities like New York, Chicago, etc., where about 1.5 to 2 square feet per K.W. is the average, partly on account of the boilers being installed in two tiers and partly on account of the individual units being of enormous capacity

and occupying comparatively small floor space. The height of the boiler room depends upon the height of the boilers themselves and also upon the depth of the basement, if one is adopted, while the design of coal bunkers is also an important controlling factor.

There being many advantages in having a basement, one is therefore decided upon for this plant, the depth of which is 13 feet from the boiler-room floor to the basement floor, this giving about 11 feet clearance between the basement floor and the bottom of the boiler-room floor beams.

Assuming that the boiler chosen is of the horizontal inclined water-tube type, with a total height of 18 feet, and allowing the requisite space above the boiler for smoke flue and the steam piping leading from the boilers to the main header, the clear height from the operating-room floor to the bottom of the roof truss will be 40 feet. This gives ample space for the installation of coal bunkers above the firing aisle.

In deciding the height of the generating room, the traveling crane and its necessary clearance of the roof truss, and especially the space required for hoisting the machinery while erecting and dismantling the turbines, have to be taken into consideration. The heaviest part of the 750-K.W. turbines or a 1,000-K.W. machine, which may be the future unit, may be easily handled by a ten-ton crane. As a power crane is little used in this size of plant, a hand-operated crane is sufficient. A clear space of 6 feet is required from the top of the runway to the bottom of the roof trusses. The elevation of the crane runway above the operating-room floor will be 24 feet. This height of course depends entirely upon the type of turbine adopted.

It is assumed that a horizontal turbine is selected. In order to have a proper condenser arrangement, the latter should be placed directly below the turbine in the basement, which will also contain the condenser auxiliaries, piping, etc. The height of this basement is also 13 feet, giving a total height from basement floor to roof truss of 43 feet. This arrangement will give the greatest convenience, as both boiler-room and turbine-room floors are on the same level.

As the generating room and the boiler room are of different heights, as shown in the cross-section (Fig. 3), the roof trusses for both rooms must be designed separately. The extended crane columns at the division wall will support the inside ends of both roofs, the pitch of the roof truss depending upon the character of material adopted for roofing, which in the present case will be reinforced concrete covered with tar and gravel. The pitch will therefore be one inch in one foot, thus giving a height of 3 feet at the end walls and 8 feet at the partition wall.

The coal is brought to the plant on the railroad siding and dumped into bins at the side of the boiler house. These bins run the entire length of the boiler house and are fifteen feet wide. In order to protect them from rain and snow, a light corrugated iron awning is built on a steel frame, all sides being left open so as not to obstruct the natural light of the boiler room. From here the coal is brought into the suspended coal bunkers by means of the conveyor system. At the side of the generating room an area runs the entire length of the building in order to give sufficient light and ventilation to the basement. The wall of this area, as will be seen in the cross-section, acts as a retaining wall. In order to strengthen this wall braces are placed every 16 feet.

These braces are of concrete 15 inches deep by 8 inches wide, reinforced by two ¾-inch rods. Around the top of this wall is installed an iron pipe railing.

Below the basement floor, between the turbines, is a trench 6 feet deep by 4 feet 6 inches wide, containing the circulating water intake and discharge pipes. As the main generating room is divided by the crane columns into 16 equal spaces, each about 16 feet, and as about 25 feet are required for the switchboard itself (four panels), 48 feet in the middle of the generating room will be left exclusively for switching purposes, both in the basement and on the main operating-room floor. As already pointed out, the space set apart for switching purposes is 10 feet wide. At each side of the switchboard, symmetrically placed, is the main entrance adjoining the superintendent's office and the locker and toilet rooms, while below these rooms, respectively, are store-room and repair shop, and the oil storage and filtering room.

Location of Plant. — As the plant runs condensing it is of the utmost importance to locate the building as near to the water edge as possible. Therefore in choosing a site these two items should be taken into careful consideration, namely, railroad connections and convenient water supply. Further, the character of the soil is an important factor in the selection of the site, as pile driving, excavating, blasting, etc., should not be excessive for a plant of this size. It is always a paying practice to make careful soundings and tests of the soil before the property is bought. Testing holes should be driven, according to soil, some 20 to 30 feet and even deeper. It is important to have this work carried on under skilled supervision and by one familiar with the particular locality. Test loads may be applied to determine the bearing power of the soil. In laying out the plant it is important to have the generating room lie next to the water supply where possible, in order that the condenser water intake may be as short as possible. Should the plant be situated on a residential street running parallel to the river it will be necessary to have the generating room face the street. It is further desirable, where possible, to have the generating room on the north side of the plant in order to have the best light.

Foundation Work. — If the site contains quicksand it should either be removed and replaced by filling, or piles should be driven, upon which a monolithic concrete mat should be laid. The latter is an expensive affair and may be accomplished either with wooden or concrete piles. In recent years it has become common practice to employ the latter, either plain concrete or reinforced, as they have a comparatively greater carrying capacity and durability, and, further, their heads may extend far above ground water. In case wooden piles are used their heads must be cut below ground water and thus deep excavation may be necessary, to which point the foundations must be carried down. If the soil should be partly of rock and partly alluvial, the latter must be carefully replaced or tamped down with layers of sand, each layer being wetted before another is applied. All rock must be cleaned before concrete is applied.

These features being satisfactorily accomplished, the size of the foundations for the various machinery and the footings for the building may be determined. In cal-

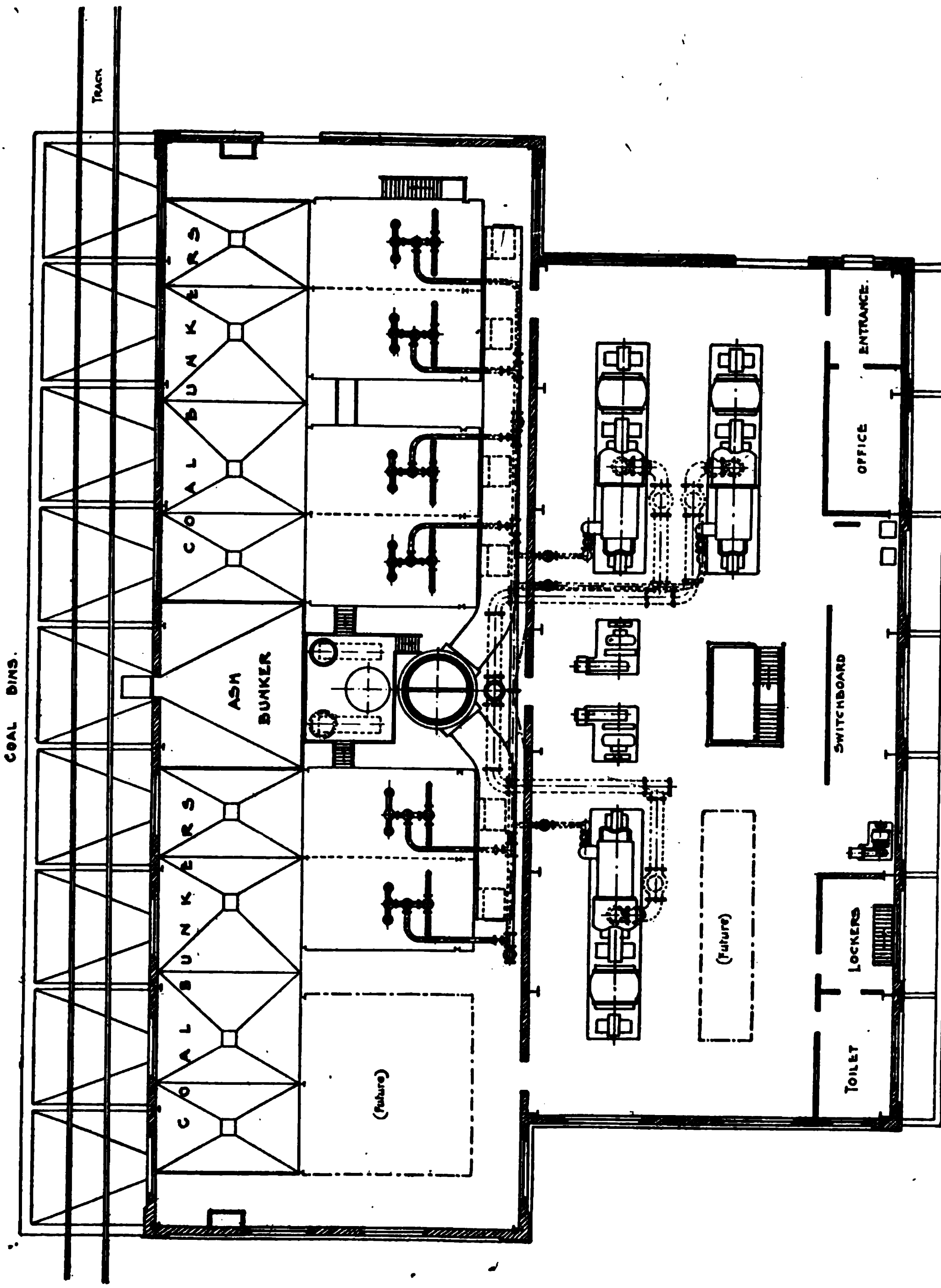


FIG. 2. Plan Showing General Arrangement of Equipment (*Electrical Review*).

culating the foundations for the machinery as well as for the building walls, the weight of the foundation itself must not be overlooked. The sizes of the foundations for the machinery are usually given in the manufacturer's drawings. Attention, however, must be given to secure the weight of the machinery, as the particular condition of the soil affects the size of foundation. In figuring the foundations for boilers and other similar apparatus, it is important to make allowance for the water contained therein. Two tons of total bearing load per one square foot of dry ordinary sand is considered an average figure. Each case, however, should be treated separately and the above figure should not be followed blindly.

In specifying the mixture of concrete, usually 1:3:6 is taken for machinery foundations; 1 being first-class Portland cement, 3 being clean, sharp sand, and 6 being crushed bluestone that will pass through a two-inch mesh.

Where anchor bolts have to be used for securing machinery, they must, together with the plates, be directly embedded in the foundation. Such bolts are required for the footings of the boiler and building columns and the various auxiliary machinery. The turbine itself does not need anchor bolts. At least one-half inch should be allowed for grouting after the material has been placed. The concrete forms for duplicate machinery may be used repeatedly. In placing the concrete it should not be allowed to fall more than 8 to 10 feet, as there is liability of the stones becoming separated from the cement and being surrounded with water, thus giving a poor bond. In addition to this the concrete should be tamped.

Should the building be located where concrete is difficult to obtain and where first-class brick is at hand, these bricks should be of hard-burned clay laid in thin layers of high-grade hydraulic cement. The foundation of the building, if located below ground water level, should be provided with some sort of waterproofing. The footings of boiler and wall columns should lie below or flush with the basement floor. Attention will be called to the fact that frequently these footings are extended some 3 or 4 feet above the floor level, which is much more expensive than running the steel columns down to the floor level, and has the further disadvantages of being always an obstruction, giving many corners for the accumulation of dirt. Under these conditions it is difficult to run circulating water pipes, drain pipes, etc., at the floor level along the building wall.

Superstructure. — The superstructure of the power plant should be as simple as possible, yet pleasing in appearance. Fireproof is one of the first considerations, and this is best obtainable by adopting a skeleton steel structure with concrete or brick walls. The roof, windows, doors, etc., should also be of fireproof material. The latter two items are frequently neglected in plants of the capacity here described.

As to whether a steel skeleton building should be adopted, the following items will be considered: The first cost of such a building is a small percentage more than that of a common brick or concrete building, when the latter has to carry steel roof trusses, crane runways, etc., but far greater rigidity is obtained. The installation of suspended coal bunkers, the connection of floor frames, platforms, galleries, etc., are much more

easily accomplished in a steel building. Pipe supports and anchors are easily arranged. By using a steel skeleton the thickness of the building walls will be reduced about fifty per cent. With this type of building when brick is used 13 inches thickness will be sufficient for the walls. In monolithic concrete walls reinforced with "expanded metal" or "wire cloth," a thickness of from 6 to 8 inches will be sufficient, provided that these walls do not, as frequently happens, act as retaining walls. This part of the wall, however, must be thicker according to the pressure of the soil. Pilasters are required to enclose the steel columns, which are set half in the walls, thus at the same time giving a possibility for artistic design. In some localities, especially in tropical zones, it may be advisable to use corrugated iron in place of brick or concrete, on account of the frequent shocks and earthquakes. In this case it will be best to build all walls as well as the roof of the same material. This type of building, however, requires frequent painting and repairs, and is not pleasing to look upon.

The steel skeleton for the building may be either of the self-supporting type, in which case light curtain walls are used, or the walls may be self-supporting and carry the steel work. When designing the steel work proper care should be taken to secure thorough bonding of the steel work and the walls. The entire building column may be enclosed in a pilaster or only a part of it, depending largely upon the choice of building material. Brick or monolithic concrete may easily partly or completely enclose the building columns, while in the use of the hollow concrete block it is desirable to have as few specially designed blocks as possible, and it is, therefore, important that the building columns do not break the inside lines of the walls. Anchorages may be secured by placing light rods on the extended flanges of the columns and bonding them between the concrete blocks. The various steel columns should always be of the open type and of simple design, so as to secure easy access for painting and inspection. Cross or X bracing is frequently found between the boiler columns in the basement, but this practice is employed only by steel constructors unfamiliar with power-house operation.

In designing the floors of the boiler and generating rooms a load factor of 250 pounds per square foot may be employed, as the entire weight of all machinery is carried by the foundations, which are built up from the basement floor. This load factor may also be applied to the switching-room floor, etc. Sufficient and conveniently located stairways should be provided. Care, however, must be exercised that they do not block up passages required for the easy operation of the plant. As the condensers and various pumps are located in the basement, it is good practice to provide at least one large opening in the floor in order to facilitate removal of the machinery by means of the overhead traveling crane. This opening at the same time will give additional light and ventilation for the basement. In the case under consideration this opening will be located between turbines in front of the exciter units in the middle of the plant.

In the spacing of the crane columns care must be taken in order to secure equal spaces and symmetry in the window arrangement. As the building is 113 feet long, seven bays of about 16 feet each will make a good layout and at the same time an

economical crane run-way construction. As the crane capacity is ten tons, 18-inch beams are required for the crane runway.

It is common practice with water-tube boilers to suspend them on steel structures, which are furnished with the boilers. As, however, an overhead coal bunker is to be installed, these front columns must be replaced by heavier ones.

In the power plant in question it is necessary to install two groups of boiler-bunkers, one on each side of the chimney, one for each. These bunkers have V-shaped bottoms in order properly to empty. They have a capacity of five tons per running foot and are made up of $\frac{5}{16}$-inch or $\frac{3}{8}$-inch material, provided at the bottom with cast-iron outlets, to which are connected the coal "down takes" to the boilers.

The roof truss has been touched upon in determining the height of the building; it remains, however, to go more into detail. Provision has to be made for chimney, exhaust pipes and vent pipes, etc., all of which must be provided with collars, and after the pipes have been erected, rain hoods must be installed. Four ventilating hoods should also be provided on the roof of the boiler room, but for the generating room such ventilators are not required, and are undesirable, as they are liable to leak, and a small leak may result in a serious shut-down of the plant. From the top of the coal bunker to the roof itself a light plastered wall will serve to keep the dust from the boiler operating room. On one side of this enclosed coal-bunker room an iron grate walk will provide easy access to the coal conveyor system. Steel stairs and bridges will be installed between the boiler batteries, while short ladders from the boiler room will give access to the coal bunkers. In front of the chimney, between the boilers, and some 8 feet above the operating-room floor, is erected, on steel columns, a platform 12 feet square, on which are placed a "make-up" tank, the purpose of which will be seen later, and two feed-water heaters, only one of which is placed for the present equipment. Stairways lead up to the platform and from here to the top of the boilers.

Masonry Work, etc. — If brick of a good quality is cheap in the locality where the plant is erected it will be wise to use this material; 12- to 13-inch walls, with pilasters some 4 feet wide by 4 to 8 inches deep will be sufficient for the walls in the present case. The wall in the basement must be correspondingly heavier, depending, of course, as already pointed out, on whether it acts as a retaining wall or not. Window and door sills and lintels should be of granite or concrete blocks, as also should be the coping, the latter being 6 inches thick.

Adopting the most modern practice in engineering under ordinary circumstances for this particular building, the entire walls, floors and roof should be monolithic concrete, reinforced partly with iron and "expanded metal," or it may be the so-called "wire cloth." In this type of construction, first of all, skilled carpenters are required for making the forms, which skill is measured by the ability to build a form which may be easily put together and taken down, as each form may be used from twenty to thirty times and even more before the building is completed. Further, skilled supervision is necessary in order that the concrete shall be properly mixed and the expanded metal properly placed, also that the concrete may be well tamped into place. The mixture of concrete being 1:2:4, four being trap rock passing through a one and one-half inch

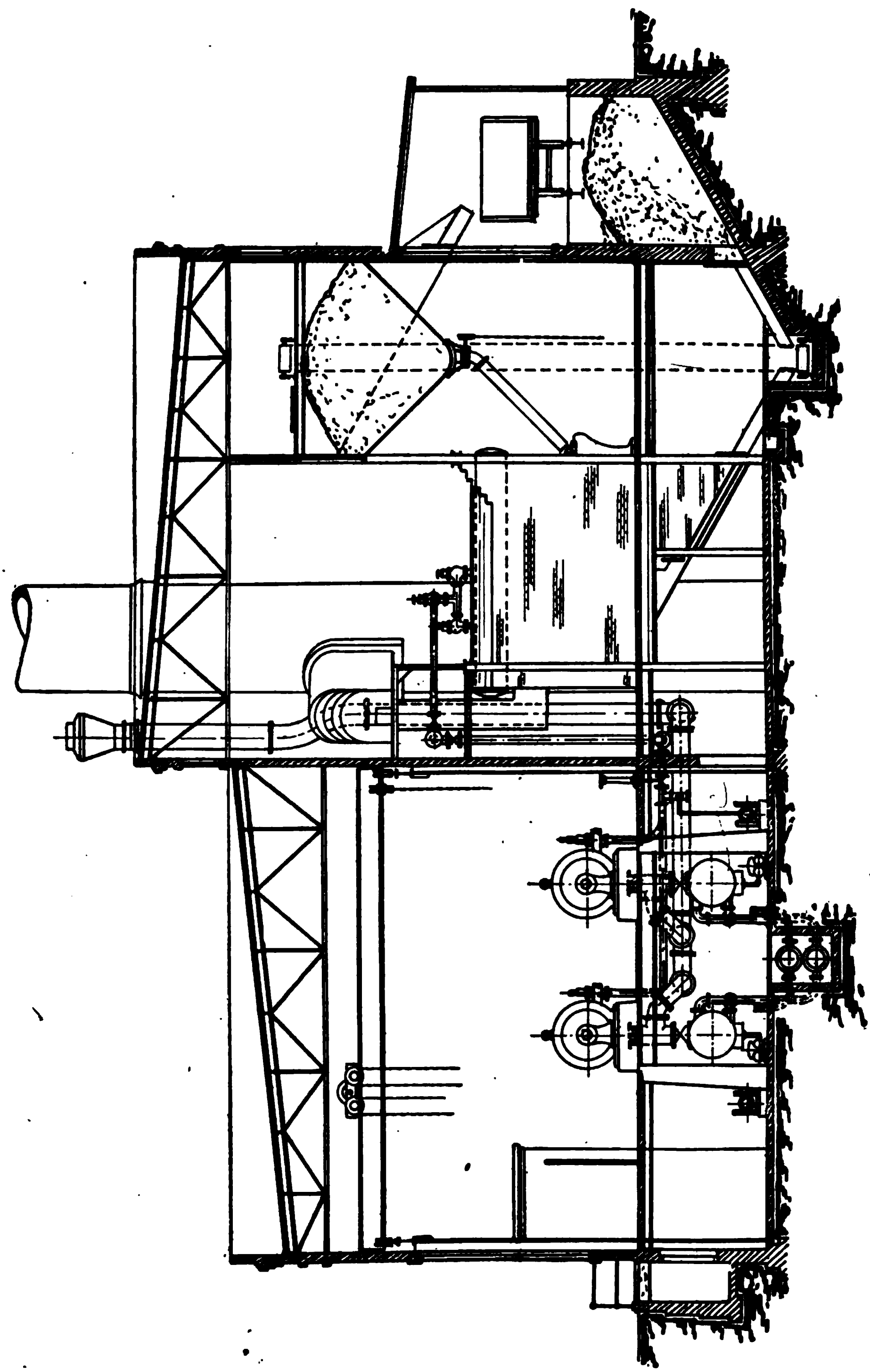


FIG. 3. Cross-Section (*Electrical Review*).

mesh, and the stone must be worked away from the form in order to obtain a smooth surface. The basement walls, whose mixture of concrete is 1:3:6, do not require any reinforcement other than some three $\frac{3}{4}$-inch rods embedded in the lintels of the doors and windows. The walls above the operating-room floor will be 8 inches thick and will contain one layer of expanded metal, three-inch No. 10, which is so placed that at both the vertical as well as the horizontal joints the expanded metal is overlapped one foot. It must be properly secured to the columns. The lintels in the doors and windows will contain $\frac{3}{4}$-inch rods, similar to those in the basement, in addition to the expanded metal.

All floors for boiler room, engine room, etc., must be designed for a uniform load of 250 pounds per square foot, the beams being located 5 inches below the floor level, this space being filled with concrete reinforced with one layer of expanded metal, six-inch No. 4. The size of floor beams, of course, depends upon the spacing, and the distance between them should not be more than 6 feet. Much care should be exercised to properly locate all holes in the floor for pipes, etc., in order to avoid unnecessary cutting of the floor and expanded metal. These holes should be provided with cast-iron thimbles in order to secure a proper finish.

The roof will be made of a layer of three and one-half inch concrete reinforced with expanded metal, three-inch No. 10. This roof may be made up of reinforced concrete slabs made on the ground and hoisted up into place, or, preferably, of one monolithic mass. After this is finished the roof will be asphalted and graveled. Also, care must be taken here in locating all openings for exhaust pipes, vents, etc., and light iron thimbles should be installed around the chimney and the various pipe openings.

Each roof will be provided with two five-inch leaders run on the inside of the building wall in order to protect them from frost. These leaders should be run as inconspicuously as possible and away from all electric apparatus. This latter precaution must be taken not only on account of the liability of leakage, but as the difference in temperature between the inside and the outside of the pipe may collect water which, dropping upon the electric apparatus, may result in a serious shut-down. In fact, frequent short circuits occurring from this cause have proven very difficult to locate.

Sanitary and Architectural Features.— Much attention may profitably be devoted to the sanitary features of the design. Cleanliness is one of the most important factors in the successful operation of a plant, resulting in more ease in obtaining first-class workmen, raising the general moral tone of the men and fostering general satisfaction among the employees.

The floors in the generating room, in the basement, will be provided with proper drainage by giving them a slight pitch toward the circulating water trench which is covered with perforated iron and connected to the sewerage system. Where this is undesirable the drainage may be accomplished by the installation of several twelve-inch by twelve-inch sumps interconnected by a three- or four-inch tile pipe. On account of the large amount of water dripping down from the ash hoppers there will be a trough in the basement floor of the boiler room running the entire length of the

boiler room, draining into a collecting basement. The rest of the boiler-house basement floor will be pitched toward this trench. As already pointed out, column foundations above the floor level should be avoided as much as possible. The drainage from the roofs and the waste pipes from the plumbing fixtures may be easily emptied into the main sewer or the river.

The toilet facilities should consist of two closets, three urinals, two enameled iron wash basins and one galvanized iron sink. At one side of the toilet room there should be two shower baths. Each shower-bath compartment should be divided so as to serve for dressing also. Open plumbing should be used exclusively and walls and floors should be of white tile. White or light color is chosen for the toilet room in order to make dirt conspicuous. The locker room will be cut off from the toilet by a partition wall. This room will contain some dozen lockers eighteen inches by twenty-four inches and about six feet high. They will be constructed of wire netting mounted on light angle-iron frames. As the toilet and locker rooms are located on the main floor of the generating room on the side farthest from the boiler room it may be reached from the latter by passing through the basement and up a flight of stairs directly into the locker room. In the office of the superintendent there will be placed one open plumbing wash bowl of white porcelain, with a toilet cabinet.

Proper means of ventilation for the boiler room will be secured by mounting four ventilating hoods in the roof, while sections of the main windows are arranged for opening on hinges. A number of small windows opening on the generating-room roof, combined with the lower windows on the opposite side of the room, will assure an excellent natural ventilation. Windows are also provided above the coal bunkers, as will be seen in the cross-section. (Fig. 3.)

The roof of the generating room will not be provided with these hoods, as such devices or louvers are liable to leak, resulting in serious interruption of the service. For the same reason the windows in the switching room are so designed that they cannot be opened, while all other windows, especially the large ones in the end walls, are arranged to swing open on a horizontal axis.

The architectural features of a power plant are usually grossly neglected, and it is the opinion of the author that it costs practically no more to create a well-designed, pleasant-looking building than a simple, plain structure with windows and doors arranged entirely out of harmony. If the power plant is located in a manufacturing district the structure should be of such a design as to give relief to the eye, but where the building is in a residential section it should at least harmonize with the architecture of the neighborhood.

As the building is made of reinforced concrete, the forms should be designed as simply as possible. Therefore all window and door sills will be straight, while the water tables, pilasters and cornices will be all of straight pattern, as shown in the elevations. (Fig. 1.)

The pilasters, window and door lintels are well projected beyond the building-line, while prominent cornices will finish the building. This will harmonize with the tall chimney, also of concrete, rising practically from the middle of the building. The

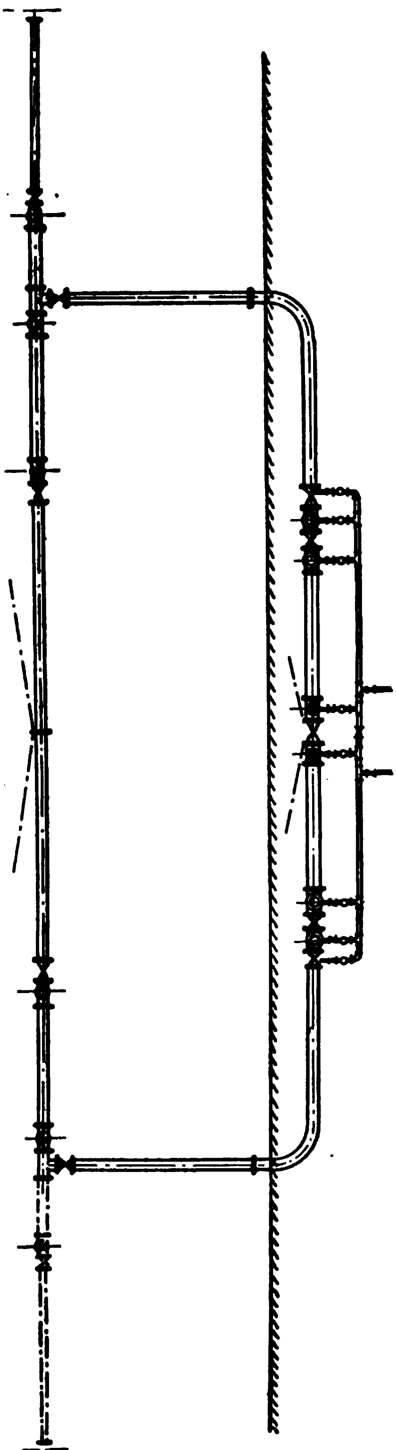


FIG. 4. Piping System (*Electrical Review*).

entire building is finished with a cement wash in order to give a uniform color.

It is of equal importance to look for a pleasing interior appearance of the plant. The first thing attracting the attention is a good general layout and general arrangement of the main prime movers on the operating-room floor. In the plant under consideration the turbines are arranged two on each side of the plant, while the two exciter units are arranged directly in the middle of the plant. In front of these is the stairway leading to the basement. For the sake of appearance the turbines are chosen, two right hand and two left hand as will be noticed in the plan (Fig. 2). The exciter units are chosen in the same manner. Besides this the steam ends of the turbines are placed end to end in the center of the room. All piping is carried below the floor, thus avoiding the objectionable appearance of exposed piping. The floors themselves are covered with light gray-colored tiles, while the walls of the generating room, for a height of some six feet, are also finished in cream-colored glazed tile. A brown border will finish the wainscoting, thus giving a pleasing contrast to the whitewashed walls. All steel work, such as columns, roof trusses, traveling cranes, etc., have a uniform green color. The windows themselves are well arranged and symmetrically placed with regard to the columns, while the switchboard will be, according to American practice, of enameled slate. The apparatus itself is well arranged upon the various panels in order to secure as perfect symmetry as possible. While it may seem extravagant at first thought to finish the floors and walls in tile, this is a comparatively small item of the total cost of the plant, has always been considered

standard practice in Continental design and, in fact, is being adopted by American engineers as the best policy.

Coal and Ash Handling Systems. — As already mentioned a raiiroad siding is brought alongside the boiler house. The cars are brought up a small incline above the coal bins extending the entire length of the boiler house. These bins are divided into nine compartments corresponding to the placing of the building columns. As will be seen in the accompanying illustration, these bin floors have a slope of forty degrees toward the boiler house and empty through chutes to the coal conveyor below the basement of the boiler room. The advantage in dividing up these bins is that the coal may be stored according to grade. Directly at the first bin a scale is provided in order to keep accurate account of the coal supply. A bucket conveying system is designed for running below the basement floor of the boiler room, up the end wall, over the entire length of the coal bunkers and down the other end wall, thus forming a complete endless chain. The vertical sections of this system on both end walls, for the sake of appearance and to avoid accident, are encased in sheet-iron shafts. The bucket coal conveyor system with a maximum speed of fifty feet per minute will be operated by a 15-horse-power, three-phase, 220-volt induction motor. A tripping device is placed on the running rail of the conveyor system above the coal bunkers, thus enabling the operator to discharge the coal in any one of the suspended bunkers. The suspended coal bunkers are designed for a coal storage capacity of five tons per running foot, and are suspended from girders running from column to column. The total coal storage capacity in the suspended bunkers will be about 480 tons, which will be sufficient to run the eight 275-horse-power boilers for eleven days, figured on a basis of four pounds per boiler horse-power hour for twenty-four hours' continuous operation. This figure, of course, depends largely upon the grade of coal used and upon the system of firing. Besides the above coal storage capacity a still greater capacity is obtained in the bins at the side of the boiler room, where some 540 tons will be stored, thus giving a total coal storage capacity of over 1,000 tons.

As already mentioned, all coal brought into the plant is weighed on a track scale, while no provision is made for measuring the coal dropping from the suspended bunkers to the hoppers of the mechanical stokers. The reasons for this design are as follows: weighing the coal at the stoker hoppers would necessitate the crushing of the coal before it was deposited into the suspended bunkers which would require a crusher for each of the nine bins, unless the coal, as delivered, was small enough not to clog these scales. In addition to these crushers, mechanically operated screens would have to be installed so as to make it impossible for large lumps to enter the scale. Where, however, small-size anthracite is used exclusively, crushers are not necessary and suspended bunker scales may be advantageously employed. Although the writer is very much in favor of keeping close record of the coal consumed in each furnace, when large-sized coal is burned it may be weighed in the railroad car, dumped into one empty coal bin, from there conveyed to an empty coal bunker and fed to the boilers. It must, however, be remembered that when large-sized coal is burned, whether it is anthracite

or bituminous, it must easily pass through the coal down-takes to the boilers. The down-take is a cast-iron pipe sixteen inches in diameter and is provided at the bottom of the bunker with a gate operated from the main floor by means of a chain.

The ashes are carried away by the above-described conveying system, as will be seen from the accompanying illustration. A large ash hopper will be installed under each boiler, constructed of structural steel and masonry work. Chutes similar to those on the coal bins will be installed on these ash hoppers and will also be provided with cut-off gates, so that when coal is being conveyed the ashes may be held in the hoppers. After the ashes are received in the conveyor they may be dumped into the main ash hopper above the boiler-room floor occupying the 23-foot by 19-foot space in front of the chimney, between the suspended coal bunkers. From this main ash hopper a spout runs through the boiler-room wall so as to empty the ashes into the empty coal car. The capacity of the suspended ash hopper is greater than that of one standard coal car, and assuming the volume of ash to be about 10 per cent of the coal burned, one car of ashes must be removed for every ten cars of coal delivered.

As the ashes are frequently wet in the boiler ash hoppers and as it is important that the water be not carried along in the conveyor system, a drainage trench has been arranged in front of the boiler columns, as will be noticed in the accompanying cross-section (Fig. 3).

In order to remove the collection of soot from the boilers, a special cast-iron hopper is connected directly to the ash hopper. The soot will discharge from here through the ash hopper and will be carried away in the conveyor with the ashes. Special precaution must be taken to keep the gate in the soot hopper as tight as possible in order that no air may enter the boiler at this point, as this would reduce the efficiency of the boiler plant.

Boilers, etc. — As already pointed out the boilers are arranged in one row, two in a battery. The boilers are designed for a working pressure of 200 pounds. Each boiler consists of two main steam drums and a number of inclined water tubes, the whole being suspended from two pairs of beams supported by steel columns. The boiler walls themselves are carried on structural steel also partly supported by the above-mentioned columns.

As the boilers have a heating surface of 2,750 square feet, about fifty-six square feet of grate surface is required, assuming that anthracite of about 1,250 to 1,350 British thermal units per pound is used. As the plant is located where skilled labor is difficult to obtain, over-feed mechanical stokers (steam driven) will be installed, and may be either of the chain grate or inclined type. Between the water tubes and the drums will be inserted a superheater capable of raising the temperature of steam, at 175 pounds pressure, 150° Fahr.

Between the upper row of water tubes and the superheater is a fire-brick partition with a damper so placed that the gases may pass either through the superheater or below the partition, thus in case of emergency allowing the superheater to be cut off and thus protected from excessive heat. It will, therefore, be seen that if the superheater

should be damaged by the negligence of the operators it will still be easily possible to operate the boiler, supplying saturated steam, as proper means have been made for by-passing the superheater.

Each boiler is provided with two 2½-inch blow-offs, connected to a 3-inch main pipe which discharges into a blow-off tank, 4 feet in diameter and 5 feet high. At the boiler each blow-off pipe is provided with a blow-off cock and an additional cut-off valve, controlled from the main operating-room floor. The blow-off piping and the blow-off tank itself are located in the basement. The tank is provided with a vent connected to the atmospheric exhaust pipe and a drain pipe emptying into the sewer system. Each boiler is provided with two safety valves mounted on the cross-over piece connecting the two drums. The necessary gauges and water columns will be installed for each boiler.

Boiler Feed-Water Supply. — The make-up tank, as already stated, is located in the boiler room on a platform some eight feet above the floor level. It is six feet in diameter and seven feet high, and will receive all the water from the condensers and the house pumps, and is provided with an overflow. In case the condenser fails to work properly and no water is supplied by the hot well pumps, the house pumps will not be sufficient to furnish the entire supply and a five-inch city main connection is, therefore, provided for the make-up tank. Where this cannot be secured the boiler feed pumps have to draw their water directly from the circulating water pipes or from some other source, such as a well. Under ordinary conditions the boiler feed pump draws its water from the make-up tank and pumps it through the heater, which is mounted upon the platform, to the boiler. With the original equipment only one closed heater is installed receiving the exhaust from all the auxiliary machinery, by means of which a feed-water temperature of 180° to 200° Fahr. is obtainable.

Two boiler feed pumps will be installed, each having a capacity of 550 gallons per hour, running at low speed, this being sufficient to supply four boilers, assuming 40 pounds of water per boiler horse-power. This apparently excessive pump capacity is chosen because after the pump has been in operation for some time, on account of the wear on the plunger, etc., the supply will not be quite up to the full rated capacity. The type of pump adopted for this purpose has four single-acting plungers of 4½-inch diameter and 8-inch stroke, while the steam cylinders are 6 inches in diameter, the steam connections being 1½ inches and exhaust 2 inches.

The main boiler feed piping runs above the boiler drums suspended from the boiler and coal bunker columns. From here 2½-inch pipes lead to the boiler drums. These latter pipes are provided with a check valve placed between two globe cut-off valves. In the steam pipe near the feed pump is inserted a pressure regulator connected to the main boiler feed pipe by means of a small pipe in order to automatically control the supply of boiler feed water.

The return of the hot well pumps, all exhaust pipes of the auxiliary machinery leading to the heater, the heater itself and the boiler feed-water pipes are covered with 85 per cent asbestos — magnesia.

Flues and Smokestack. — In order that the space between the rear of the boilers and the division wall should not be made excessively wide the smoke flue is run above the boilers, since on account of the installation of the suspended coal bunkers there was ample space for this design. As will be seen in the cross-section (Fig. 3) the individual boiler breechings are carried straight up into the main flue. As the breeching has a sectional area of 8.5 square feet (0.31 square feet per boiler horse-power) and extends some distance in back of the drums, it will be noticed that sufficient space is left for reaching the manhole. The smoke flue itself is carried on structural steel supported partly on the division wall and partly on beams suspending the boiler. The expansion of the main smoke flue amounts to approximately 2 inches. An expansion joint has been placed between boilers No. 2 and No. 3. As the plant is not completed on the other side of the stack, no expansion joint is installed there. The expansion joint is of the sliding sleeve type with bolts and slots. Attention must be called to the fact that this joint must be made as nearly air-tight as practicable, as any leakage here will materially decrease the draft below the furnace. The cross-section of each main flue is 36 square feet with arched top, the flue itself being made up of $\frac{3}{16}$-inch rolled plates reinforced by $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$ inch angles. Cleaning doors are provided at the end of each floor for removing soot.

The amount of draft is regulated automatically by means of dampers placed in the breeching of each boiler. The main flues are not provided with dampers, therefore one damper regulator is depended upon for operating the entire plant, the above-mentioned dampers being connected by one common rod which is operated by the regulator located between boilers Nos. 4 and 5.

The total ultimate capacity of the boiler plant will be 2,200 horse-power, and assuming a coal consumption of four pounds per boiler horse-power, the height of the chimney will be 175 feet and the diameter 8 feet according to Kent's table. As there are two smoke flues it is necessary to erect a deflecting wall up to some 2 feet above the smoke flues. The chimney itself is made of reinforced concrete having an inner and an outer shell, the former going up only to a point about 30 feet above the entrance. This inner shell has a thickness of 5 inches while the outer shell up to this same height is 7 inches thick. Between the two shells is an air space of 4 inches. The remainder of the chimney is constructed with a single shell 5 inches thick. Both shells are reinforced vertically as well as horizontally by iron rods or small T-irons, the mixture of concrete being one part cement to four parts sand, no crushed stone being employed except for the base.

The chimney is properly protected by a lightning rod and provided with iron rungs on the outside, giving access to the top. It is frequently claimed, especially by concrete chimney builders, that rungs are not required with this kind of chimney; the author is of the opinion, however, that they are very essential, and as it is difficult to place them in a 4-inch concrete wall, especially when forms have to be removed and replaced, he would suggest the use of rungs, in the form of a rectangle extending through the chimney shell and forming steps inside and outside. At the base of the chimney a clean-out door is provided.

Steam Piping. — In order to draw either saturated or superheated steam from the boiler the cross-pieces from the two drums of each boiler are connected to the nozzle of the superheater, by means of two angle globe valves and a T fitting, as will be seen in the cross-section (Fig. 3) of the plant. As the pipes lead to one common header and as the pressure from one boiler may easily vary, a non-return angle valve is directly mounted on the above-mentioned tee. From here a 4-inch pipe leads to the header, which is 7 inches in diameter. It would have been an easy matter to have brought the pipes from the header through the division wall directly to the throttles of the turbines nearest the boiler room, while in carrying over to the other turbines in this manner difficulty would have been experienced in supporting and draining the pipes, and it would certainly not have improved the appearance of the plant. The author, therefore, decided to bring two 7-inch steam down-takes below the main operating-room floor, connecting them here, by means of a short header, in order to form a complete ring. From this lower section, as will be seen in the pipe drawing (Fig. 4), as well as in the cross-section (Fig. 3), 5-inch pipes run below the generating-room floor, rising through it to the turbines. A similar arrangement has been made for the exciter units. The auxiliary machinery, such as the circulating water pumps, house pumps and hot well pumps, draw their steam from the main steam pipe leading to its turbine. These pumps operate under the same steam conditions as the turbines, while the boiler feed pumps and the two small house pumps are operated also with steam of the same character, except that this steam will contain a small amount of water which has been collected from the entire pipe system, the steam for these pumps being drawn from the bottom of the lowest main header and the piping therefore acting at the same time as a drip system. There are no further traps or similar features for draining the remainder of the system. The reason for this is that, first, the steam does not contain much water, which would not interfere with the operation of pumps of this character, and, second, one does away with the trap system. However, the supply pipes to the pumps must be provided with a bleeder. It will be seen in the accompanying piping sketch (Fig. 4) that the upper header does not have any drip pipe at all and the small amount of condensation will run down into the lower header, where all tees and outside ends of valves are connected by a ¾-inch globe valve and an additional check valve to a short 1½-inch header from where the pipe leads to the above-mentioned pumps.

In order to secure a proper operation and so that any section of the pipe may be easily cut off in case of emergency, non-return valves must be placed near the boiler. The 4-inch pipes leading from the boilers to the header may be cut off at the header by gate valves, while in the header itself, at the junction of boiler No. 4 and boiler No. 5, are inserted two 7-inch gate valves. One valve would have been sufficient were it not for the condensation in the pipe, as the latter dead section of pipe is 45 feet long and under ordinary operating conditions does not carry any steam. On each end of the steam down-takes valves are also placed. Besides this there are valves inserted at the branches leading to the turbine and exciter engines in order to cut out any section of the pipe in case of emergency. The supply pipes to the turbines have additional gate valves close to the units, controlled by stands on the operating-room floor.

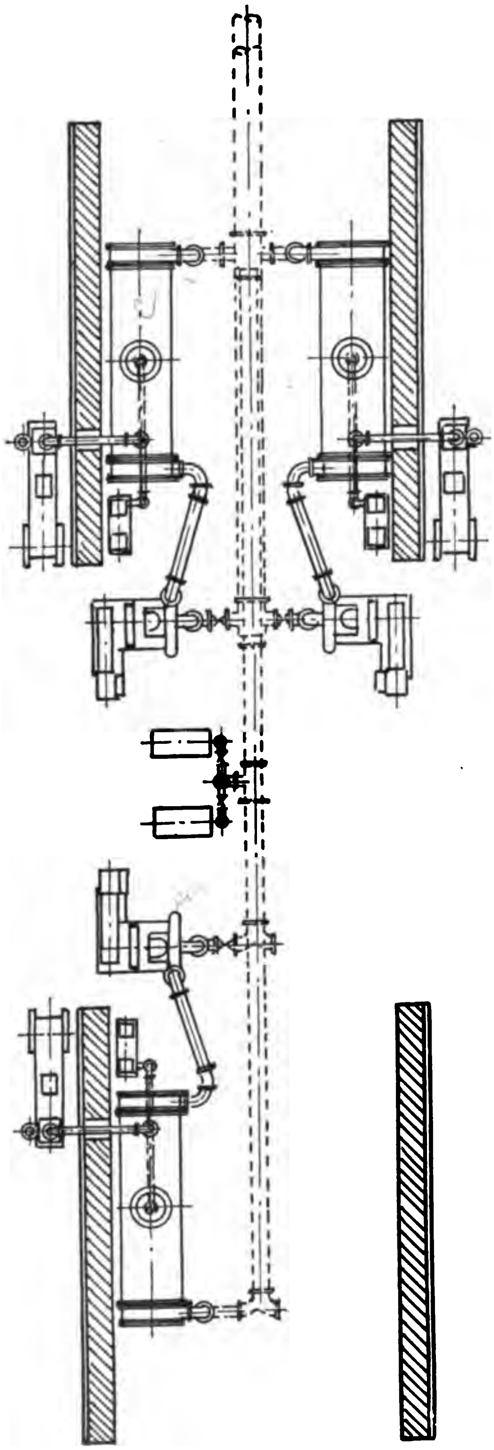


FIG. 5. Condenser Plant (*Electrical Review*).

The upper as well as the lower header pipes are well anchored on the crane and building columns, and have been indicated on the plan (Fig. 2), as well as in the pipe drawing (Fig. 4). This has been done, first, on account of vibration, and, second, on account of expansion. As the anchors are located in the middle of the piping, the expansion has to extend toward both ends. The expansion of one side (60 feet) will be approximately 2 inches and will be easily taken up by the 4-inch pipes leading from the boilers to the header, while the expansion of each half of the lower header, each of which has a length of about 35 feet 1.2 inches, is taken up by the steam down-takes, which are some 23 feet long. It will therefore be seen that no expansion loops are necessary. The lower steam header, as well as the pipes leading to the turbines, is carried from the floor beams above, while the upper steam header is easily suspended from the steel structure carrying the smoke flue. A platform will be erected directly beneath the latter header in order to give easy access to the various valves. This platform will be carried by the division wall at one end and the beams, from which the boilers are suspended, at the other end.

Returning to the size of steam pipes, the following data were employed in the calculations, as the manufacturers guarantee a steam consumption not to exceed 17 pounds per K.W. hour, normal load

for rated capacity, and as approximately 10 per cent of the total steam consumption is used for auxiliaries, etc., the 20 pounds assumed in the beginning of the article is a safe assumption. As the volume of dry saturated steam at 175 pounds pressure is 2.4 cubic feet per pound, the total volume of steam per turbine per hour would be $275 \times 17 \times 2.4 = 11,220$ cubic feet, giving a velocity, in a 5-inch pipe, of 7,000 feet per minute. Under ordinary operating conditions dry saturated steam is not used, but steam superheated about 150° Fahr., which increases the volume approximately 30 per cent, thus giving a lineal velocity in the same size pipe of 9,100 feet per minute.

Even though there is considerable difficulty at times in securing fittings for 5-inch piping (the greater bulk of pipe being steel), it would be poor practice to use one size larger (6 inches), as the velocity would be only 6,500 feet for superheated steam, while the velocity in a 4-inch pipe would be too great for American practice, although frequently used on the Continent, where higher degrees of superheat are common practice. For the same reasons, and taking well into consideration the steam consumption of the auxiliaries, 4 inches was chosen as the size of pipe from the boilers to the header.

As four 4-inch pipes are approximately equivalent in carrying capacity to one 7-inch pipe, a 7-inch pipe is therefore chosen for the header or ring system.

The pipes will be covered with a thin layer of asbestos cement upon which is laid 85 per cent asbestos-magnesia sectional covering, held together with galvanized iron wire. Over this an 8-ounce canvas covering is securely sewed and finally painted with fireproof paint.

Turbines and Generators.—The turbines will be of the horizontal type, connected direct to the generators and both mounted on a common bedplate. They are arranged, as will be seen in the plan (Fig. 2), side by side, with steam ends toward the middle of the room. The steam connections are 5-inch; each turbine is provided with a screen and throttling valve. After the steam has passed through the turbine it exhausts into the condenser through a 24-inch outlet.

On account of the small weight of the turbo-generator and as much space is required in the basement for condensers and their auxiliary machinery, these turbines are carried in pairs on 18-inch beams, which in turn are supported on two concrete walls, thus giving ample space between and around the condensers and securing a good pipe arrangement.

Pressure oil to the bearings of the turbines is supplied by a small pump operated from the main shaft of the turbine and mounted on the main bedplate. After the oil has passed through the bearings, it is returned to a cooling and filtering system and used over again. The turbo-generator has a normal capacity of 750 K.W. and has an overload capacity of 50 per cent; it is of the revolving-field, alternating-current type, and at 1,800 revolutions per minute has 7,200 alternations per minute (four poles), thus giving sixty cycles per second, suitable for lighting, power and railway service — for which purpose this plant has been designed. The voltage is 2,300. Due to the

high velocity of these turbines, a "closed" type of generator is employed on account of the otherwise very objectionable noise. This necessitates a ventilating system which is secured by bringing a fresh-air duct in under the main operating-room floor to a point directly below the generator and discharging up through the bedplate. Air is drawn from the area at the side of the building, the duct being turned downward and protected with a netting so as to prevent the entrance of any foreign substances.

Condenser Plant. — The arrangement of the condenser plant depends upon the arrangement of the turbines, as the former is placed directly below the latter. Each condenser is supported on two I beams, in turn supported by the small concrete piers and the turbine foundations. The exhaust of the turbine is so arranged as to discharge into the condenser or to the atmosphere. For this purpose an atmospheric relief valve is placed in the exhaust pipe as near to the turbine exhaust outlet as possible. A gate valve is placed between the free exhaust and the condenser, so that in case of repairs to the latter or its auxiliaries the turbine may be operated and exhaust direct to the atmosphere. Particular pains must be taken to avoid any leakage on pipes under vacuum, as this will materially affect the latter. A corrugated copper expansion joint is therefore placed between the turbine and condenser, as will be seen in the cross-section (Fig. 3), to take up the expansion, which amounts to about ⅛ inch. The exhaust inlet to the condenser is 24 inches in diameter, while the free exhaust pipe from each turbine is 14 inches. The latter size has been chosen to obtain a steam velocity of 5,000 feet per minute. All exhaust piping up to the atmospheric relief valve is of cast iron; the flanges, after being carefully bolted together, are painted with shellac or asphaltum, while the rest of the exhaust piping, with the exception of a few fittings, are made of spiral riveted pipe. As will be seen in the plan (Fig. 2), the two 14-inch pipes of the two turbines are connected to one pipe 20 inches in diameter, leading into a 20-inch riser terminating a few feet above the roof in an exhaust head. This arrangement allows two turbines to discharge at the same time to the atmosphere, while, under unfavorable conditions, all three turbines may do the same.

It is common practice to allow 4 square feet cooling surface per K.W. of turbine capacity, thus giving 3,000 feet for the surface condensers. This apparently large surface is chosen, as at times muddy or comparatively warm water is supplied. Under the above conditions and in order to obtain from 28 to 29 inches vacuum (barometric reading 30 inches), the liable figure of 70 pounds of water to condense one pound of steam will be assumed, and figuring the velocity in the centrifugal pump at 450 feet per minute, a 10-inch pump will be required. As there will be, when the plant is completed, four condenser outfits, and as the velocity in the main circulating water intake must be about 300 feet per minute, a 20-inch pipe will be required. In order to have more uniformity in the size of pipes, the circulating water discharge pipe will be the same size. Both pipes, after supplying the first two condenser units, are reduced to 16 inches. It will be noticed in the accompanying condenser plan (Fig. 5) that two small house pumps also draw their water from this pipe line. The duty of these pumps, as has already been touched upon, is to make up the water lost by leak-

age at the boiler, consumption of the auxiliary machinery, etc. These pumps are 6 × 4 × 6 inches and have 3-inch suction and 2½-inch discharge pipes. The circulating pumps, having a 10-inch suction and discharge, are operated by a single-cylinder horizontal engine (ten inches by ten inches), and as the velocity of the circulating water to the condenser must be reduced, the pipe leading to the latter is 12 inches in diameter. The steam supply pipe to this engine is 2½ inches and the exhaust 3 inches.

The exhaust steam enters the condenser at the top, and as the condenser is of the counter-current type, the cooling water enters at the bottom and is discharged at the top, where a 12-inch connection is made to the main discharge pipe, located below the intake pipe in the trench, and emptying into the river. After the pumps have been started a siphon is formed and the pumps are required to overcome friction only. Both intake and discharge pipes are made of cast iron and outside of the power house are embedded in the earth. The intake pipe must be provided with a screen and a foot valve. The circulating water pumps will be primed by means of the air or dry vacuum pumps.

These latter pumps are located outside of the turbine foundations, as will be seen in the condenser plan (Fig. 5). The air pumps are connected to the condenser by means of a 4-inch pipe and discharge through a 3½-inch pipe into the main atmospheric exhaust pipe. A dry vacuum pump 6 × 14 × 10 inches will be required, the steam connection being 1¼ inches and the exhaust 1½ inches.

On the bottom of the condenser is a hot well, where the condensed steam is collected. From here the water is drawn away through a 3-inch suction pipe by means of a duplex pump (5 × 4½ × 5 inches) and discharged through a 2-inch pipe into the make-up tank. These pumps start automatically by means of a regulator in the hot well.

Exciters and Air Compressor. — To secure a continuous operation of the plant two exciter units are necessary, one of which is always kept in reserve. As the ultimate total capacity of the plant is 3,000 K.W., one per cent, or 30 K.W., will be the required capacity of each exciter, this taking into consideration the fact that the latter cannot be overloaded to the same extent as the main units. As practically all the auxiliary machinery is steam driven, the exciters are operated by 8 × 8-inch horizontal engines, the steam connection being 2½ inches and the exhaust 3 inches.

For the purpose of blowing out the generators and switchboard apparatus, an air compressor is installed at one side in the switching room. This is driven by means of a chain from a 5 horse-power motor mounted on the frame of the compressor.

Switchboard and Wiring System. — As already stated, the switchboard is located in the middle of the generating room on the side wall. The generator feeders run under the floor direct to the oil switches, which are suspended from the generating-room floor, from where they lead through one main slot to the rear of the switchboard. The switchboard itself is made of marbleized slate mounted on a steel frame. There are four generator panels, each 24 inches wide, two exciter panels, each 16 inches wide,

and eight feeder panels for lighting and power, also each 16 inches in width, and one panel for the sectionalizing switches, this latter being 32 inches wide. This gives a total length of switchboard of about 25 feet.

In order to secure a flexible system and at the same time insure continuity of service and proper protection for the entire equipment, the following apparatus is mounted on the various panels. Three of the generating panels, the fourth being left blank for a future unit, each contain three ammeters for reading the current in each phase, one wattmeter, one field ammeter, and one power-factor indicator; these six meters being arranged in two vertical rows on the upper part of the panel. A recording wattmeter is mounted for convenience on the back of the board. Below the above-mentioned meters on the front of the board are symmetrically arranged one field switch, one potential receptacle and plug, one synchronizing receptacle and plug, one three-pole, double-throw oil switch operated by hand, and one rheostat wheel. The generator panels are mounted at one end of the board and on the outside panel is placed a swinging bracket containing one wattmeter, one synchroscope and two synchronizing lamps. Adjoining the generator panels are the two exciter panels, each containing a voltmeter, ammeter, rheostat wheel and a two-pole, single-throw knife switch, the equalizing switches being mounted directly at the machines.

Upon each panel for the outgoing feeders is mounted a three-pole, single-throw oil switch in order to draw current from either of the two sets of buses, and an ammeter and voltmeter, a wattmeter being unnecessary, as the power may be measured at the sub-station.

A special lighting panel will be installed at the side of the office in the switching room, as shown in Fig. 2. This panel will be 32 inches wide, with the following mounted on the front: one double-pole knife switch for each lighting circuit and one double-pole, double-throw knife switch so that the lighting buses may be thrown on to the exciter buses or on to the secondary of a special lighting transformer. Near this transformer is mounted its oil switch. There is also a small three-phase transformer for supplying power to the coal conveyor and air-compressor motors with the main oil switch mounted at the transformer and local knife switches mounted at each motor.

The accompanying diagram (Fig. 6) shows the main features of the wiring diagram, small details, such as the location of meters, etc., being omitted. It will be seen that the bus-bars are cut up by means of sectionalizing switches at four different places, one being between the outside generators and two being between generators No. 2 and No. 3. This latter precaution has been taken in order that interruption of the lighting and motor circuits may be reduced to a minimum. It will be seen from the diagram that the entire system is laid out as symmetrically as possible, and sufficient switches have been placed so as to make the system as flexible as possible, and in order to meet any emergency which may arise in the plant itself or in the outgoing feeders.

The double bus-bar system has been adopted for the same reason as the ring system in the steam piping. Both the wiring and piping systems are the main arteries in

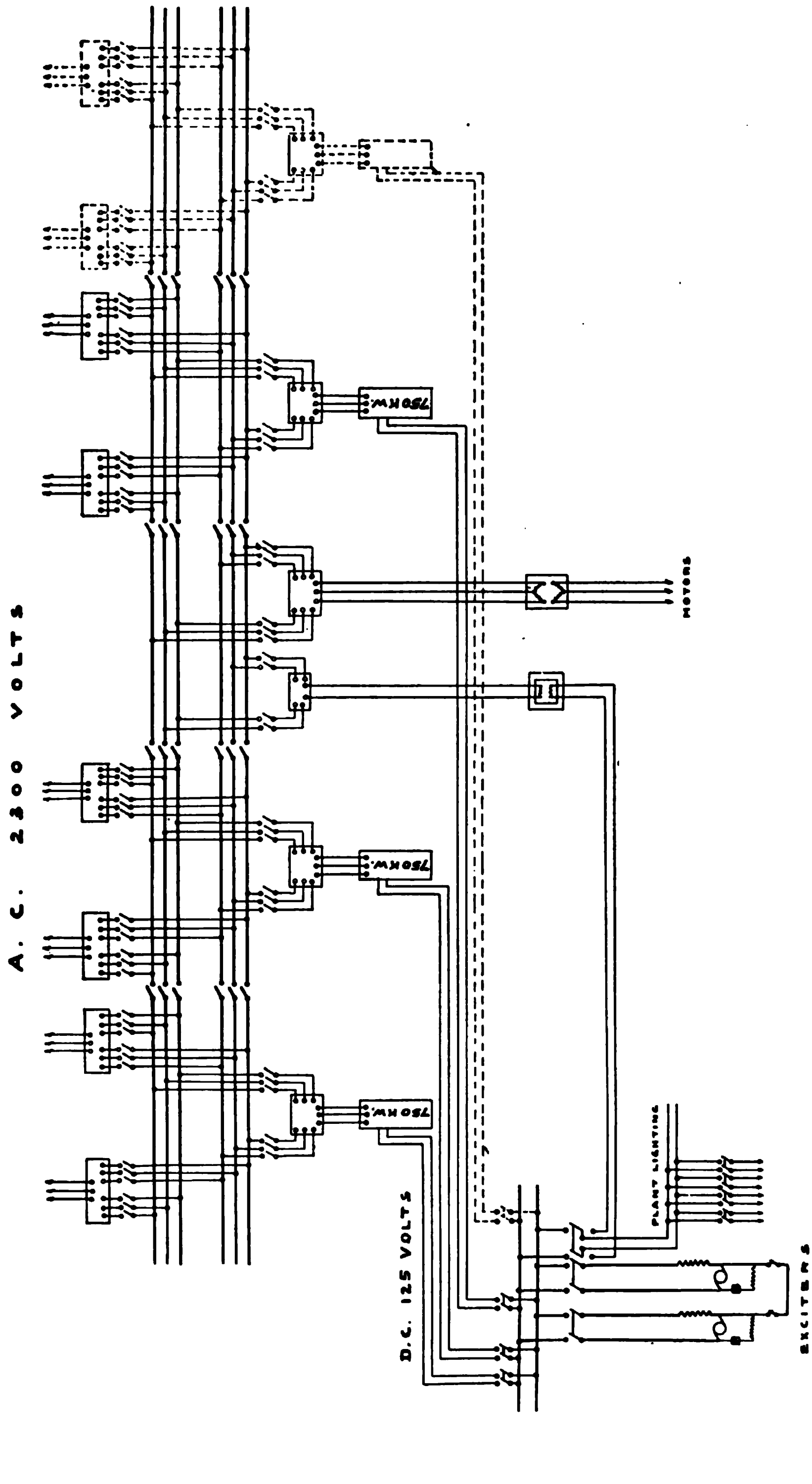


FIG. 6. Wiring Diagram (*Electrical Review*).

their respective departments, upon which depends largely the effective and continuous operation of the plant. Current may be thrown into either of the two buses or on both at the same time, and the outgoing feeders may draw from one or both sets. One bus-bar system may serve exclusively for light and the other for power, the outgoing feeders leading underground to the various sub-stations where the current is transformed to voltages suitable for either light or power.

Conclusion. — To give an exact figure of the cost of this plant is impossible, as it depends so largely upon the location. As this plant has been designed with the best possible equipment, using all first-class material and with the point in view of reducing the working force to a minimum, assuming that the site is convenient for securing labor and shipping facilities, the price of the plant, with the complete ultimate equipment (3,000 K.W.), would approximate $390,000, or $130 per K.W. normal rating. This figure is the result of a comparison of the actual costs of a number of similar plants which have come either directly or indirectly under the author's charge. Increased size and capacity of a plant may reduce the first cost to about $100 per K.W., depending, of course, as stated, upon the size of the plant. An alternative for reducing the cost of the plant, which unfortunately is too frequently adopted, is to simplify the general layout. Such plants are built for the purpose of putting them in operation as soon as possible, securing a large number of customers and selling the plant with a large profit, regardless of operating economics. For following this scheme the author would suggest the following simplifications, and by adopting these the plant may still be run satisfactorily, but the number of employees and operating expenses will be increased, while the first cost will be decreased some $50,000 or $60,000, making about $100 per K.W. Do away with boiler-room basement, suspended coal bunkers and suspended ash hopper, coal and ash handling conveyor system, mechanical stokers, and also the track scale for weighing the incoming coal. The coal cars may be brought on a trestle higher than shown in the cross-section, so that the coal may drop from the car and slide through an opening to the boiler-room floor or be shoveled on to it. The ashes will be carted away from the main operating-room floor. With this arrangement the height of the boiler room will be decreased 20 feet. At the same time the generating-room basement and area-way at the side of the building may be omitted, in which case the turbines would be installed on frameworks built up so as to leave space for the condensers, etc., underneath, and small pits dug so as to accommodate the hot well pumps.

The pipes, such as mains, steam, exhaust, blow-off, etc., will be placed in trenches. The piping system may be simplified by omitting some of the valves, and also the provision for drawing either superheated or saturated steam. In fact, the superheaters themselves may be omitted. Another saving could be effected by simplifying the bus-bar system, using a single instead of a double system. As the space in the basement used for switching purposes, repair, store, locker rooms, etc., has been done away with, a two-story compartment will be required for this purpose. The second story, of course, will be installed directly above the main switchboard, and over the

entire length of the generating room. From the total height of the generating room 13 feet will be saved.

Instead of the generating-room floor being tiled, it may receive a granolithic cement finish. Also the tiled wainscoting around the room may be omitted.

Of course, a case might arise where the installation of condensers and their auxiliaries would be unadvisable, depending upon the character of the water supply. Before laying out the plant a close study of this feature should be made.

A still further decrease in first cost could be obtained by doing away with the steel columns and having only the roof trusses of steel, the wall being of brick instead of reinforced concrete, the crane runway resting on brick pilasters.

If the plant were to be built on the Continent, where the operating conditions are considered of greater importance, and where still better results are desired than those obtainable with the original equipment, the following design would have been adopted:

No stokers would have been installed, as labor is easily obtainable so skilled as to produce one horse-power-hour for one and a quarter pounds of coal at 12,000 British thermal units per pound. The turbines are sold with the guarantee that the steam consumption will not exceed nine and a half to ten pounds per indicated horse-power-hour when using a high degree of superheat at 175 to 200 pounds pressure and a vacuum of not less than 27 inches, and everyday practice proves that these guarantees are strictly lived up to. Superheaters will be installed capable of furnishing steam at a total temperature of 650° to 700° Fahr., which would not cause any extra deterioration in the turbine. All auxiliary machinery will be motor driven, and a small storage battery will be installed for supplying light for the station and exciter current in case of emergency. As, however, warm water is required for boiler feed, economizers will be installed in the basement, where also the smoke flue will be arranged. Smoke flue and chimney will both be built of brick.

Owing to the higher temperature of the steam a greater velocity will be secured, and the size of pipes will be decreased. The wiring system will be a more complicated one.

Assuming that the total water consumption of this plant, including auxiliaries, leakage, etc., is 17 pounds per K.W.-hour (a very unfavorable figure under Continental conditions) and the water consumption for the above-designed plant of 20 pounds per K.W.-hour, there will be a saving of 3 pounds effected. On account of the fact that the plant is for both lighting and railroad purposes, and will, therefore, have a widely fluctuating load, we will assume that the total daily output of the 3,000-K.W. station is only 30,000 K.W.-hours. Assuming further that one pound of coal evaporates eight pounds of water, and that the coal cost $2.50 per ton, a saving of $4,180 will be effected per year. This is a net saving of fifteen per cent of the total coal consumption.

CHAPTER IX.

TESTING POWER PLANTS.

General Considerations. — All plants, even though they be of small capacity, should undergo a rigid test in order to prove the manufacturer's guarantees. This guarantee test should be made as soon as possible after the plant is completed, as it is upon this test as a rule that the final payments depend. The test should be conducted or watched by the designer of the plant, so that he may see and rectify any weak point that may appear in the design, besides acquiring valuable experience for future plants. If a designer desires to advance himself, he should watch the operation of the plant.

All tests should be made public in the technical press, so as to give a comparison with similar plants; it is of importance also to publish an unsatisfactory test, so that the same mistake will not be duplicated, besides bringing about a discussion among able engineers whose ideas may rectify the error. It may seem that by thus advertising the failure of any piece of apparatus, the manufacturer will be injured. This supposition is erroneous, as the manufacturer will thus be forced to improve his machine.

Preparation for Boiler Tests. — The boiler should be tested as to its economy and capacity. Before starting the test, the boiler and its auxiliary apparatus should be placed in first-class working condition; all soot, dirt and ashes should be removed from the boiler tubes and chambers, the tubes cleaned of any deposits of scale, and the grates thoroughly cleaned of clinkers, ashes, etc. Tests for air leaks in the boiler setting should be made, and any leaks around poorly fitting doors made tight. This last is doubly important, if induced draft is used.

The coal used for determining the performance of a boiler must be of the same kind as that to be used in the plant when running. From the coal to be burned samples should be taken for analysis, as described in the chapter on coal. The ashes should be properly collected and weighed when dry. Proper analysis should also be made of the smoke; this analysis is usually made by an expert chemist, but with modern instruments the engineer may accurately determine its character. This matter is more thoroughly discussed in the chapter on combustion.

For measuring the feed water weighing tanks must be installed. Meters are seldom used, except for checking purposes. Thermometers should be placed in the feed lines. All pressure gauges must be properly checked before starting a test, as

they are subject to great fluctuations. The feed and blow-off piping should be exposed, so that if any leak occurs it may be detected; all connections to other units should be blank flanged.

The test should be run a sufficient length of time to minimize any slight inaccuracy in starting and stopping. The condition of the boiler, furnace, etc., should be the same, as nearly as possible, at the end as at the beginning of the test. The water level and the quantity and condition of the fire should be the same as well as the steam pressure and the temperature of the boiler setting and flues.

Method of Boiler Tests. — There are different methods of starting and stopping tests. In starting, first raise the steam to the required pressure, note the water level, then draw the fire, and as quickly as possible start a new one with weighed wood and coal, accurately noting the time. When the test is completed, note the water level and the time, remove the entire fire, which should be burned low, and clean the ash pit. If the water level is not the same as at the start; correction may be made by computation, but not very accurately unless the temperature is the same. Water in a boiler has a higher coefficient of expansion than the boiler.

Another method is to start by thoroughly cleaning the fire, noting water level, pressure and time, covering the fire with weighed coal just before which the ash pit should be cleaned. Before the end of the test the fire should be burned low, so as to be in the same condition as at the start, steam pressure, water level and time should then be noted. All other conditions, such as setting and flue gas temperature, must be the same at the finish as at the start. Provision should be made to remove the steam as fast as it is made, so that the rate of evaporation will be constant. Attention should be given to the discipline in conducting a test, so that all orders issued by the man in charge be promptly and intelligently obeyed by the operating force.

The test readings should be made at frequent and uniform intervals, and recorded on a chart. All small details should be noted and time taken. The time and style of fire should be kept uniform. The accompanying report of a test on a 350-horsepower Stirling boiler at the Public Works Company, Bangor, Maine, gives essential items for making a complete boiler test.

RESULTS OF TEST.

Date of test, March 4th P.M., and 5th A.M., 1898.	
Duration of test, in hours	10
Dimensions and proportions:	
Grate surface, square feet	68.66
Water heating surface, square feet	3,500
Ratio of water heating surface to one of grate surface	50.97
Average pressures:	
Steam pressure in boiler by gauge, pounds	121.1
Steam pressure absolute, pounds	135.8
Barometer pressure in inches of mercury	29.99
Barometer pressure in pounds per square inch	14.75
Force of chimney draft in inches of water	0.29

Average temperatures:

Temperature of air outside, deg. F.	30
Temperature of fire room, deg. F.	58
Temperature of the steam at pressure, deg. F.	350.4
Temperature of escaping gases (Gauntlett Pyrometer), deg. F.	482.5
Temperature of the feed water (well in the feed pipe), deg. F.	186.6

Fuel:

Kind of coal used: Big Vein Cumberland.	
Total amount of coal from the pile, pounds	13,802
Moisture by samples, per cent	15.36
Moisture in total coal, pounds	2,120.6
Dry coal fired under the boiler, pounds	11,681.4
Total refuse, ashes, cinders, etc., pounds	638.0
Percentage of refuse in dry coal, per cent	5.46
Total combustible used, pounds	11,043.4
Dry coal consumed per hour, pounds	1,168.14
Combustible consumed per hour, pounds	1,104.34

Calorimeter tests:

Quality of steam, dry steam being taken as unity, per cent	99.44
Moisture in steam, per cent	0.56

Water:

Total weight of water pumped into the boiler and apparently evaporated, pounds	121,860.00
Pounds of water in steam, pounds	688.00
Water actually evaporated, corrected for quality of steam, pounds	121,172.00
Equivalent water evaporated into dry steam from and at 212 deg. F., pounds	129,770.00
Factor of evaporation	1.0709
Equivalent total heat derived from fuel, B.T.U.	125,320,000
Equivalent water evaporated into dry steam from and at 212 deg. F. per hour, pounds	12,977.00

Economic Evaporation:

Water actually evaporated per pound of dry coal, actual pressure and temperature, pounds,	10.37
Equivalent water evaporated per pound of dry coal from and at 212 deg. F., pounds	11.10
Equivalent water evaporated per pound of combustible from and at 212 deg. F., pounds	11.75

Rate of Combustion:

Dry coal actually burned per square foot of grade surface per hour, pounds	17.01
Dry coal actually burned per square foot of heating surface per hour, pounds	0.33

Rate of Evaporation:

Water evaporated from and at 212 deg. F. per square foot of grate surface per hour, pounds,	188.28
Water evaporated from and at 212 deg. F. per square foot of heating surface per hour,	3.70

Commercial Horse-Power:

Actual horse-power by the A.S.M.E. Code, 30 pounds of water per hour evaporated from a temperature of 100 deg. F. into steam of 70 pounds steam gauge pressure or its equivalent, 34.487 pounds per hour from and at 212 deg. F. per hour, H.P.	376.30
Horse-power, builder's rating, H.P.	350.00
Horse-power developed above builder's rating, per cent	7.5

Efficiency:

Heat units accounted for by one pound of coal burned (dry)	10,728.03
Heat units in one pound of dry coal, Bomb Calorimeter	13,558.00
Theoretical evaporation per pound of dry coal, pounds	13.11
Actual evaporation under working conditions of tests, pounds	10.37
Efficiency: percentage of possible evaporation realized	79.13
Theoretical loss from all sources (of the possible heat in coal), per cent	20.87

The report as given above is on a test of a boiler of average size; that of a larger size is as follows: the boiler was of 700-horse-power capacity and of the Parker type.

FEED. — The feed water was pumped directly into the boiler from the weighing tanks.

COAL. — The coal used was apparently well burned, but analysis shows that there was 6.46 per cent of the original carbon in the ash, and a somewhat higher economy would probably have been obtained if the boiler had been operated at a less horse-power.

ASH. — The necessity for using water in the furnace to prevent the formation of large clinkers makes the determination of the exact percentage of refuse, by drying and weighing the entire amount of ash at this plant, practically impossible, and samples were taken and the figures entered are from these samples. The analysis of the coal gave 17.87 per cent of ash and, making proper allowance for the unburned coal in the refuse, gave 20.18 per cent as the amount actually obtained.

CALORIFIC VALUE OF FUEL. — Samples of the coal were taken during the test and check values of the heat per pound were obtained from each sample on a Parr Calorimeter. This value was also calculated from the proximate analysis of the coal.

ECONOMIC RESULTS. — Ordinarily in determining the water evaporated per pound of combustible, all the refuse is assumed to be ash. Really the volatile matter accompanying the unburned carbon is utilized and the heat apparently obtained per pound of combustible is increased. The evaporation was reduced to the basis of combustible supplied, giving 11.85 pounds per pound of combustible from and at 212 degrees. On the usual basis this value would have been 12.674 pounds.

ANALYSIS OF DRY GAS. — The coal was properly burned and the amount of air supplied per pound of carbon was reasonable. Analyses were made once an hour. Before the test and while the openings into the furnace were not closed by the accumulated ash, the quantity of air supplied reached as high as 26 pounds per pound of carbon.

STOKER. — The data relating to the steam and water supplied to the stoker show that about .54 per cent of the heat available was utilized in heating the water used to cool the stoker. The quantity of steam used to run the stoker amounted to 5.8 per cent of the boiler capacity.

HEAT BALANCE. — The use made of the heat contained in one pound of fuel as fired is shown in this table. The balance, unaccounted for, is partly used in evaporating part of the water supplied to the ashes (1.15 pounds per pound coal) and part in radiation. An error of 5 per cent is possible in this heat balance.

DATA AND RESULTS OF THE TEST ON A 700-HORSE-POWER PARKER BOILER TO

DETERMINE THE ECONOMY OF THE BOILER RUNNING AT THE CAPACITY THAT COULD BE OBTAINED FROM IT UNDER USUAL WORKING CONDITIONS.

The boilers are set two in a battery. The boiler tested is the end one of the group, nearest the stack.

The boiler has a furnace at each end, equipped with a mechanical stoker and grate, the two grates having a common fire chamber. The two side bars and the ash plate at the bottom of the grate aro water cooled. The cooling water after use is led to a feed water heater. The gases pass back and forth along the tubes, being guided by three light tile baffles and leave the setting at the top of the boiler, passing directly into the main flue.

The burned coal falls over the ends of the grates into a common ash chamber and from there is dropped at intervals into barrows. To prevent the ash from forming large clinkers, a stream of water is distributed

over the ashes, a part of which is evaporated and the balance runs off. Unless this chamber is kept fairly full of ashes, the leakage of air into the furnace is considerable.

The tubes are 4 inches diameter, 20 feet long, and with the exception of the bottom row are horizontal. The bottom row is inclined to make a space for the superheater tubes and to carry the baffling which protects the superheater tubes from direct impingement of the flames.

There are two drums, 4 feet 6 inches diameter, 22 feet between heads, each drum having its separate set of upper, lower and superheating elements. The drums are connected below the water line at the front end.

The upper elements for each drum are seven tubes high and ten tubes wide. Their function is to heat the feed water. The feed water enters the upper element at the back beyond the check valve which prevents the water backing up in the drums. The flow is forward and back alternately in each tube in the top row, then down to the next row, etc., finally discharging through an upcast into the steam space of the drum. The water flows along the diaphragm into the "scale pocket" and back into the water chamber of the drum. When the feed is interrupted, the water for circulation is supplied directly from the drum through the check valve above referred to.

The lower elements receive this heated water and convert it into steam, counter-flow being maintained by checks as in the feed elements. The five elements to each drum are each two tubes wide and nine tubes high. The water coming down from the drum enters the header controlling two elements, passes through the check valve and then down through the tubes. The lower end of each element is connected by a separate upcast to the steam chamber of its drum.

The steam furnished by both drums is led to a fitting, from which 5-inch tubes carry it down, on each side, to the superheater headers. After passing through the superheater tubes, of which there are 64, 1½ inches diameter and 18 feet long, the steam is collected in headers and another pair of 5-inch tubes carry it to the stop valve casting. These 5-inch tubes are built in the setting. There is a flooding device and a drain on each superheater element.

The boiler was handled by the regular men with instructions to make as much steam as possible without wasting coal over the end of the stokers.

The fuel used was small anthracite.

The furnace was fired at each end of the boiler, two (2) box stokers being used, both being water cooled and steam jets used for draft.

The weather was clear and hot.

All the appliances used in making the test were standardized and all readings given below are corrected readings.

The start and stop of the test was by what is known as the Alternate Method, the boiler being run at the rate at which it was tested three hours before the beginning of the test.

Date of trial, July 17 and 18, 1905.

Duration of trial, noon July 17, 1905, to noon July 18, 1905, 24 hours.

Dimensions and Proportions.

Grate surface: 2 each, 9′ 5″ width, 7′ 3″ length. Total area 136.5 sq. ft.

Height of furnace: 3′ front end, 4′ 9½″ back end

Water heating surface: 6,600 sq. ft. tubes, 325 sq. ft. bottom of drums, 154 sq. ft. tops, total	7,079	sq. ft.
Superheating surface	378	"
Ratio of water-heating surface to grate surface	51.85	to 1

Average Pressures.

Steam pressure by gauge (145.5 before superheater)	143.3	lb. per sq. in.
Force of draft just above boiler	0.84	in. of water
Force of draft in furnace	0.55	in. of water
Barometer, 29.83 ins.	14.7	lb. per sq. in.

Average Temperature.

Of external air	87.9	deg. Fahr.
Of fire room	90.2	" "
Of steam (before superheater 363.5)	483.6	" "
Of feed water entering boiler	79.8	" "
Of escaping gases from boiler	486.8	" "
Increase in temperature of feed water due to stoker	6.65	" "

Fuel.

Size and condition: Fine anthracite.		
Weight of coal as fired	75,927	lb.
Percentage of moisture in coal	3.9	per cent
Total weight of dry coal supplied boiler	72,966	lb.
Total ash and refuse — dry	18,589	lb.
Quality of ash and refuse — apparently fairly well burned.		
Total combustible	54,377	lb.
Percentage of ash and refuse in dry coal (6.46 per cent unburned carbon, 20.18 per cent real ash from dry coal burned.)	25.5	per cent

Proximate Analysis of Coal.

Fixed carbon	77.50	per cent
Volatile matter	2.23	"
Moisture	2.4	"
Ash	17.87	"

Analysis of Ash and Refuse.

Carbon	25.34	per cent
Earthy matter	74.66	"

Fuel per Hour.

Dry coal supplied boiler per hour	3,040.2	lb.
Combustible supplied per hour	2,426.7	"
Dry coal per sq. ft. of grate surface per hour	22.27	"

Calorific Value of Fuel.

Calorific value by Parr Calorimeter, per lb. of dry coal	11,811	B.T.U.
Calorific value by analysis. per lb. of dry coal (proximate)	12,020	"

Quality of Steam.

Number of degrees of superheating	121.2	deg. Fahr.

Water.

Total weight of water fed to boiler	540,485 lb.
Factor of evaporation	1.2751
Equivalent water evaporated into dry steam from and at 212 deg.	689,172 lb.

Water per Hour.

Water evaporated per hour	22,520 lb.
Equivalent evaporation per hour from and at 212 deg. per sq. ft. of water-heating surface	4.06 "
Equivalent evaporation per hour from and at 212 degrees	28,716 "

Horse-Power.

Horse-power developed	832.3 H.P.
Builders' rated horse-power	700 "
Percentage of builders' rated horse-power developed	118.9 per cent

Economic Results.

Water apparently evaporated under actual conditions per lb. of coal as fired	7.118 lb.
Equivalent evaporation from and at 212 deg. per lb. of coal as fired,	9.0767 "
Equivalent evaporation from and at 212 deg. per lb. of dry coal supplied boiler	9.4451 "
Equivalent evaporation from and at 212 deg. per lb. of combustible supplied boiler	11.83 "

Efficiency.

Efficiency of boiler: heat absorbed by the boiler per lb. of coal divided by the heat obtained from 1 lb. of coal	82.76 per cent
Efficiency of boiler, including the grate; heat absorbed by the boiler per lb. of coal, divided by the heat value contained in 1 lb. of coal	78.34 "

Analysis of the Dry Gases.

(Volume.)

Carbon dioxide (CO^2)	7.82 per cent
Oxygen (O)	7.50 "
Carbon Monoxide (CO)	0.13 "
Nitrogen (by difference) (N)	84.55 "
Air supplied per pound of carbon	17.7 lb.

Stoker.

Water used to cool stoker per min.	7.28 gals.
Temperature before entering stoker	78.9 deg. Fahr.
Temperature after leaving stoker	119.75 " "
Equivalent rise in temperature of feed water	6.65 " "

STOKER — Continued.

Steam to stoker:	
Pressure	72.3 lb. per sq. in.
Temperature	356.9 deg. Fahr.
Pressure near outlet — front grate	28.5 lb. per sq. in.
Pressure near outlet — back grate	25.9 " "
Drop in supply pipe in 16 inches	4.8 " "
Steam used in both grates per hour	1,358 lb.

HEAT BALANCE.

Heat in 1 lb. coal with 3.9 per cent moisture from calorimeter		11,250 B.T.U.
Loss by incomplete combustion	132.2 B.T.U.	1.17 per cent
Waste in unburned coal in ash	525.4 "	4.67 "
To evaporate 3.9 per cent water	47.6 "	0.42 "
Given to water in stoker	47.3 "	0.42 "
Given to steam used in stoker	25.2 "	0.22 "
Heat to chimney gas	1,309.7 "	11.64 "
Heat to water in boiler	8,766.3 "	77.93 "
Unaccounted for	396.3 "	3.53 "

Method of Testing Prime Movers. — Engine or turbine tests are usually made to prove the efficiency and capacity of the machine. All instruments used in the test should be the best of their respective kinds and in first-class order. The steam pipes leading to the engines should be cut off from all other units, while the water of condensation from the cylinder should be separately collected and measured. The engine valves and pistons should be tested for leakage; to ascertain the character of the steam, calorimeters may be connected between the throttle and the engine, while thermometers should be placed at the steam inlet and exhaust, and if the engine be of the multiple expansion type between the cylinders also; gauges should be placed to read in conjunction with the thermometers. The thermometers and calorimeters should extend into the pipe, so that not only the steam at the surface of the pipe wall is tested, but also the steam in the interior.

The amount of steam consumed by the engine may either be calculated from the indicator diagrams taken from each individual cylinder, or from the amount of water evaporated in the boiler, in which case both boiler and engine test have to be run in parallel. In the latter case allowance has to be made for leakage and condensation in the pipe line. The steam consumption of a condensing engine may be measured in the same manner, but if a surface condenser is used more accurate results will be derived by measuring the water of condensation, in which case the indicator cards may be used as a check. The water of condensation must be carefully collected in a tank located above a second tank on a beam scale, into which the first tank is drained, weighed and discharged. These tanks, as they are only for temporary use, are usually ordinary barrels. If, however, the owners of the plant desire to test frequently while the plant is in operation, steel tanks should be provided for this purpose. There are a number of prominent plants that have this system installed.

In order to do away with the necessity of weighing each tank of water, automatic weighing tanks may be employed. This system has been installed at the new turbine station of the Potomac Electric Power Company, Washington, D.C.

Test of an Engine.—In order that the reader may become conversant with the best practice in operating tests, the following examples are submitted:

Number of trial	1	2	3	4	5	6
STEAM.						
Pressure by gauge on boiler side of engine stop valve, pounds per square inch	117.5	117.5	117.5	114.5	117	114.5
Temperature of steam on boiler side of engine stop valve, deg. Fahr.	743	738	749	726	751	732
Temperat ureof steam entering high-pressure cylinder, degrees Fahr.	601	590	569	550	580	558
Superheat of steam entering high-pressure cylinder, degress Fahr.	253	242	221	202	232	210
EXHAUST STEAM.						
Temperature at exit from engine, degrees Fahr.	120	117	104	110	97.5	93
Temperature of water leaving hot well, degrees Fahr.	102	101	78	70	71	64
Vacuum gauge, inches of mercury	26.4	26.4	27.0	26.5	27.4	27.4
POWER.						
Revolutions, by counter	100.6	100.7	100.6	100.7	100.7	100.7
Piston speed in low-pressure cylinder, in feet per minute	603.6	604.2	603.6	604.2	604.2	604.2
Indicated horse-power	481.3	461.1	347.5	145.5	333.5	258.0
HEAT ACCOUNT (from 32° Fahr.) IN B.T.U.						
Gross heat supply entering engine per minute	100,540	97,890	71,060	65,790	51,230	29,040
Heat equivalent of indicated horse-power per minute	20,410	19,550	14,734	14,140	10,940	6,170
Per cent of gross heat	20.3	19.98	20.7	21.5	21.4	21.2
DEDUCTIONS (reckoned from hot well temperature).						
Heat supplied per minute per indicated horse-power, B.T.U.	198.25	201.7	197.6	192.1	194.0	194.0
Work actually obtained for 1 pound of steam, foot-pounds	217,700	213,700	222,800	230,600	228,000	226,500
Thermal efficiency, per cent	21.39	21.02	21.46	22.07	21.86	21.86
Heat theoretically required by standard engine, Rankine cycle, B.T.U. per minute	142.4	142.5	130.2	128.0	126.0	128.5
Efficiency ratio	0.72	0.71	0.66	0.67	0.65	0.66
Pounds of steam used per indicated horse-power per hour	9.098	9.267	8.886	8.585	8.682	8.742
Equivalent consumption of saturated steam, reckoned from temperature of hot well, pounds	10.63	10.81	10.38	10.03	10.07	10.12

The test given above as reported in *The Mechanical Engineer*, and widely discussed in various other engineering papers, is a very exceptional one and brings out

the great advantage obtained by the use of superheated steam. It will be noticed that the steam consumption in the fourth test is as low as 8.585 pounds per I.H.P. hour with superheated steam, while the consumption of saturated steam under the same conditions was 10.03 pounds.

The engine tested was a vertical compound-marine type, provided with piston valves; the cylinders are not jacketed. It was built by Cole, Marchent & Morley, of Bradford, for the Durham Street Weaving Company, Ltd., of Belfast. The cylinder diameters were 21 inches and 36 inches, the stroke 36 inches, thus giving a cylinder ratio of 2.94. Steam supplied by a Lancashire boiler was superheated in an independently fired Schmidt superheater, and reheated at the engine just before entering the valve casing, thus, as will be seen by the table, enabling the steam to be superheated 253° Fahr. (test 1) when it enters the high-pressure cylinder. The exhaust of the high-pressure cylinder was again superheated before entering the low-pressure cylinder. The methods of tests and of calculations were in accordance with the recommendations of the Society of Mechanical Engineers.

Parsons Turbine Tests.—The foregoing Table I gives tests of Westinghouse-Parsons turbines of 400-K.W. to 1,250-K.W. capacity; the last column in the lower row represents a test of a 2,600-K.W. Brown-Boveri-Parsons turbine. From this table the steam consumption of the turbine may be read under various operating conditions. An explanation is hardly necessary. The table is taken from a paper read by Francis Hodgkinson before the American Society of Mechanical Engineers.

A test report of probably greater importance to the plant designer, as the performance of the machine is described, is given below. The author is indebted to the Westinghouse Machine Company for the use of this report.

The object of the tests was to specifically determine the fulfillment of the builders' guarantee of the steam consumption at various loads and under various conditions; and, incidentally, to observe the general efficiency of the steam turbine for its intended work.

The equipment ordered by Joseph Benn & Sons comprised a turbo-generating unit consisting of a 600 nominal horse-power Westinghouse-Parsons steam turbine, direct connected to a 400-K.W. Westinghouse polyphase generator of the revolving field type. Both turbine and generator are of the standard construction employed by the builders for machines of this size.

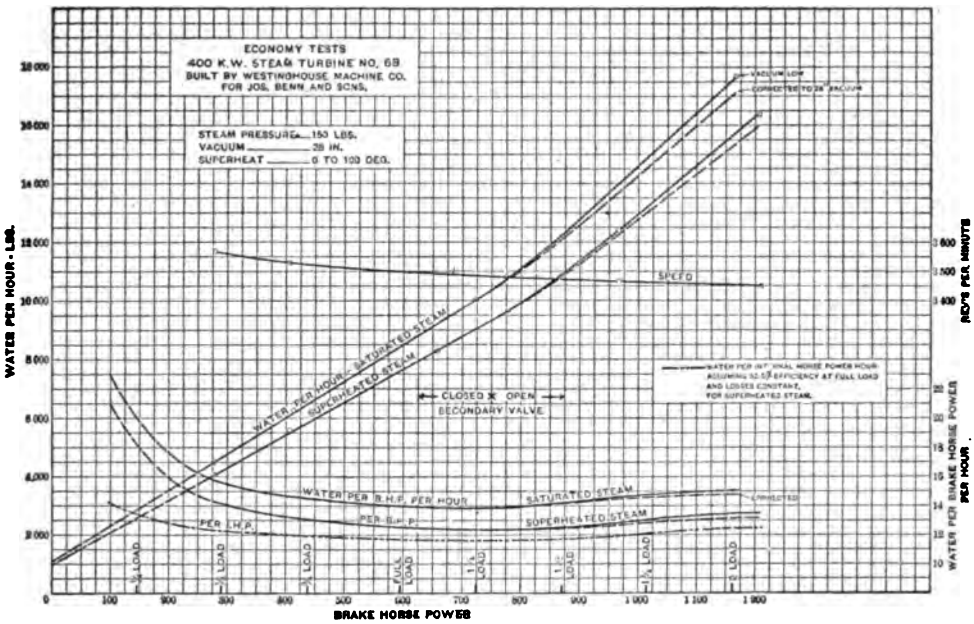
It was particularly desired to determine the efficiency of the turbine independently of the generator, consequently separate tests were made on the steam turbine and the generator. To insure the utmost accuracy, brake tests were made on the turbine. The exhaust steam from the turbine was condensed in a surface condenser and the condensed steam weighed.

Steam Economy. — The results of the eleven official economy tests conducted upon the above-mentioned 400-K.W. Westinghouse-Parsons turbine are shown in the accompanying Table II and in graphical form in Curve Sheet 1.

TABLE II. RESULTS OF TESTS — RATED FULL LOAD CAPACITY.— 400K.W. = 580 B.H.P.

Turbine No. 68.	Superheated Steam. 28" Vacuum, 150 Pounds Pressure.						Saturated Steam. 28" Vacuum, 150 Pounds Pressure.				
Nominal Load	Twice Full Load.	1½ Load.	1¼ Load.	Full Load.	¾ Load.	½ Load.	Twice Full Load.	1¼ Load.	Full Load.	¾ Load.	½ Load.
Date of test, July, 1904	8	8	8	8	8	8	9	9	9	9	9
Duration of test, hours	1	1	1	1	1	1	1	1	1	1	1
No. of test	9	8	7	4	5	6	14	13	10	11	12
Steam pressure (gauge) near throttle, lb. per square inch	152	149.6	153.2	152.7	153.2	153.1	150.85	151.6	152.6	154.8	154.7
Vacuum in exhaust pipe, in Hg.	26.6*	26.94*	27.35	27.35	27.35	27.35	26.25*	27.3	27.31	27.3	27.3
Barometer, inches, Hg.	29.32	29.32	29.32	29.32	29.32	29.32	29.23	29.23	29.27	29.27	29.23
Vac. refd. 30" barometer, in Hg.	27.28	27.62	28.03	28.03	28.03	28.03	27.02	28.07	28.04	28.03	28.07
Temp. of steam near throttle, deg. Fahr.	466.3	465.5	460.1	467	469.9	459.4	367	366.9	365.1	367.6	366.97
Superheat at turbine, degrees Fahr.	99.9	100.2	93.1	100.25	102.9	92.5	2.3	.75	2.9	1.8	2.9
Per cent moisture at throttle, per cent	......	......	......	......	......	......	......	......	......	......	......
Quality of steam to turbine	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Speed, R.P.M.	3,454.5	3,460.8	3,486	3,502.8	3,532.2	3,561.6	3,496.1	3,500.3	3,513.3	3,571.3	3,597.3
Length of brake arm, inches	20	20	20	20	20	20	20	20	20	20	20
Pressure of brake arm, net, lb.	1,102.2	882	703.7	591.76	366.7	247.5	1,052	654	592.5	366.3	247
Brake H.P. developed, H.P.	1,207.5	967.5	777.6	657.3	410.7	279.4	1,165.6	725.9	660	414.6	281.6
Per cent full load rating, per cent	208	167	134	113	71	48.2	201	125	114	71.5	48.5
Steam condensed per hour, lb.	16,365	12,377	9,652	9,207	5,522	4,005	17,632	10,060	9,169	6,242	4,468
Steam per B.H.P. per hour, lb.	13.55	12.79	12.41	12.48	13.45	14.34	15.12	13.85	13.89	15.05	15.86
Steam per B.H.P. hour (corrected for 28" vacuum), lb.	13.19	12.61	......	......	......	......	14.7	......	......	......	......
Efficiency* $\frac{\text{B.H.P.}}{\text{Int. H.P.}}$	96.21	95.3	94.2	93.4	89.7	85.5	96.1	93.9	93.3	89.7	85.6
Steam per Internal H.P. per hour, lb.	12.7	12.02	11.7	11.65	12.06	12.25	14.12	13.00	12.96	13.5	13.58

* Vacuum low. † Based upon an efficiency of 92½ per cent at full load.



CURVE SHEET I.

A comparison of the builders' guaranteed steam consumption with the results obtained under the various operating conditions with superheated steam and with saturated steam is shown in Table III.

TABLE III. — COMPARISON OF STEAM CONSUMPTION AT VARIOUS LOADS.

SUPERHEATED STEAM.

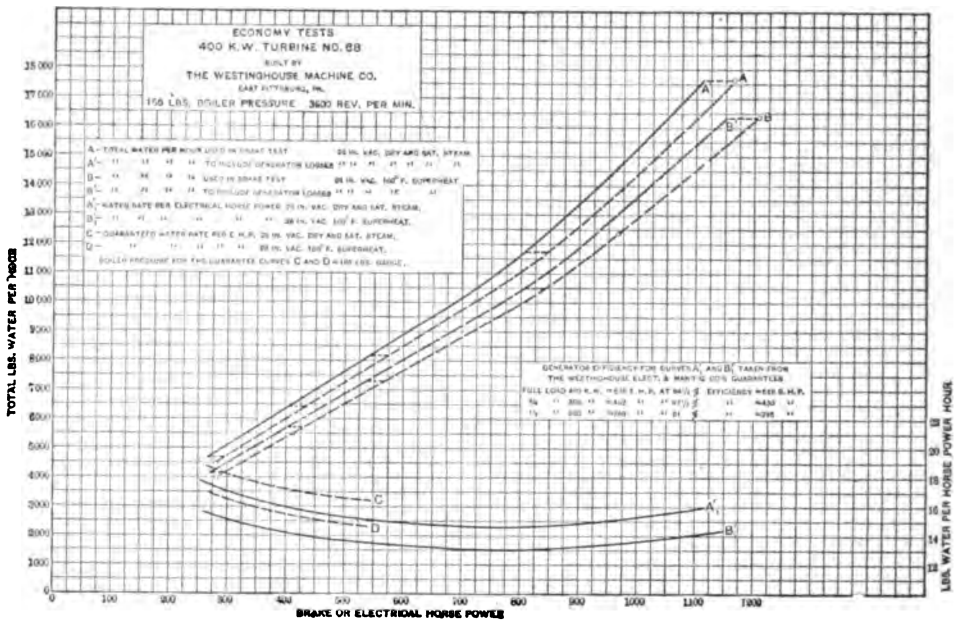
Steam at 150 lbs. Pressure and 100° Fahr. Superheat, Vacuum 28 Inches.	Lb. Steam per Brake H.P. per Hour.		
	Full Load.	¾ Load.	½ Load.
Guaranteed water rate in lb. per electrical horse-power per hour	14.8	15.5	16.9
Guaranteed generator efficiency	94.5%	93.5%	91%
Equivalent water rate in lb. per brake horse-power per hour	13.98	14.49	15.38
Lbs. steam used per brake horse-power during test	12.48	13.45	14.34
Percentage better than guarantee	10.9%	7.2%	6.7%

SATURATED STEAM.

Dry Saturated Steam at 150 lb. Pressure, Vacuum 28 Inches.	Lb. Steam per Brake H.P. per Hour.		
	Full Load.	¾ Load.	½ Load.
Guaranteed water rate in lb. per electrical horse-power per hour	16.4	17.2	18.7
Guaranteed generator efficiency	94.5%	93.5%	91%
Equivalent water rate in lb. per brake horse-power per hour	15.5	16.8	17
Lbs. steam used per brake horse-power during test	13.89	15.05	15.86
Percentage better than guarantee	10.3%	10.4%	7%

It will be noted that the actual results shown by the tests are better than the builders' guarantee in all cases.

If it is desired to obtain a fuller comparison of the results over a wider range of loads it can be found on Curve Sheet 2; curves A and B representing the actual



CURVE SHEET 2.

results obtained with saturated and superheated steam respectively, and curves C and D representing the guaranteed steam consumption.

Overload Capacity. — The tests have shown the turbine capable of carrying great overloads. It will be noted that the extraordinary overload of 108 per cent was carried by the turbine with excellent economy. This desirable feature is brought about by an automatic secondary governor valve, with which the turbine is fitted, which valve begins to operate only when the load on the turbine has reached about 700 horsepower, or about 15 per cent overload. This feature is valuable as it permits the turbine to operate at its best economy at or near full load and at the same time it provides ample means for sustaining large overloads.

Speed Reglulation. — The governor of the turbine is so constructed that its sensitiveness may be altered within broad limits. This turbine unit is intended ultimately to operate in parallel, and, therefore, required a speed regulation at or near 4 per cent.

A governor test was run with the following results:

TABLE IV.

Load.	R.P.M.	R.P.M. Variation.	Per cent of Variation.
0	3,620	+124	+3.55
½	3,541	+ 45	+1.29
Full	3,496	0	0
1½	3,460	—36	—1.03

Extreme variation, ½ to 1½ load, 2.32%.
Extreme variation, 0 to 1½ load, 4.58%.

Observations during the regular load test follow:

TABLE V.

Load.	R.P.M.	R.P.M. Variation.	Per cent of Variation, Normal.
½	3,559	+59	+1.69
Full	3,500	0	0
1½	3,475	—25	—0.71
Twice full	3,450	—44	—1.26

Extreme variation, ½ to twice load, 2.95%.

These results are shown in the speed characteristic curve on Curve Sheet 1, and are somewhat better than the preliminary governor test.

Superheat. — The effect of superheated steam upon turbine economy is well indicated by the divergence of the two water lines corresponding to the tests with saturated and superheated steam. This divergence is practically uniform. (See Curve Sheet 1.)

Expressed in approximate terms, the results of these tests indicate that the steam consumption is reduced 10 per cent per 100° Fahr. superheat throughout the range of tests.

Details of Tests. — The method of conducting the tests and the details concerning the calibration of instruments, methods of measurement, etc., are referred to below, also an outline of electrical tests upon the generator.

Methods of Testing. — In general, the method employed in testing the steam turbine conforms to the A. S. M. E. standard code, but departs in some particulars, owing to the somewhat different problems involved in turbine construction.

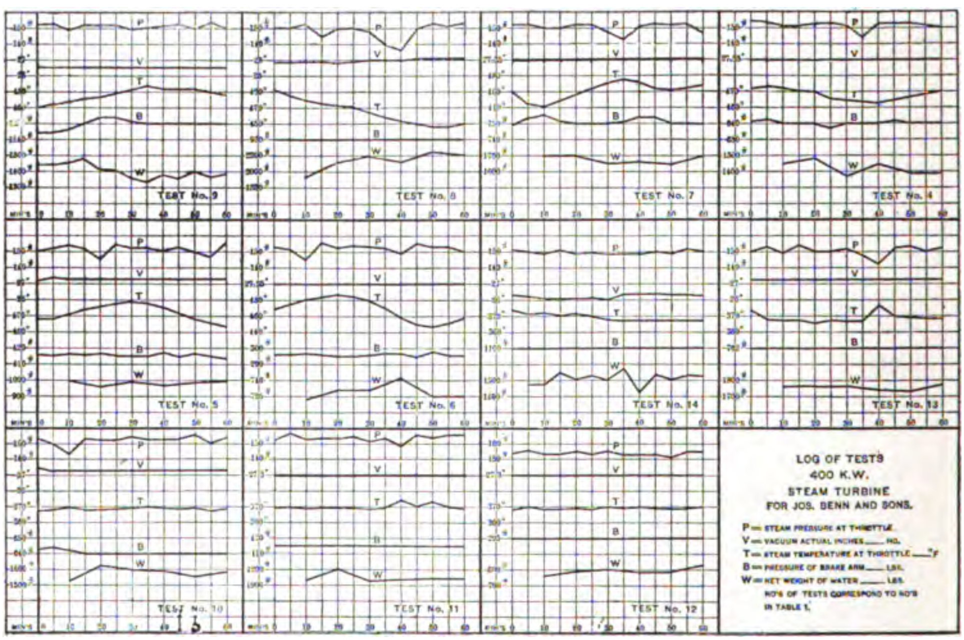
Steam was furnished from a boiler plant located at some distance; tests with dry saturated steam were therefore run with the aid of a superheater because of the large amount of condensation taking place in a long steam pipe line; thus dry saturated

steam was delivered to the turbine. As this superheater was fired by natural gas, the steam temperatures were readily maintained constant.

Exhaust steam was condensed in a surface condenser of the counter-current type, equipped with a two-stage rotative dry air pump and an independent hot well pump which later discharged the condensed steam directly into a pair of weighing tanks.

The water absorption brake used operates upon the principle of the Prony brake, and results are computed in the same manner. Its brake arm terminates in a roller bearing upon a block supported by a platform scale. Previous to the test the eccentric weight of the brake arm was determined by balancing the brake on knife-edges, this weight (about 48 pounds) being finally deducted from the observed thrust to determine the net torque developed.

Calibration of Instruments. — All gauges, thermometers and scales used in the test were carefully calibrated to insure accuracy; the pressure gauges by actual test throughout their working ranges on a Crosby gauge tester, the thermometers by immersion in steam of known pressure and temperature, and the scales by checking with a set of standard weights.



CURVE SHEET 3.

Methods of Observation. — Steam pressures at the turbine were determined by a gauge attached close to the turbine throttle; exhaust pressures,* by compensated

* On account of the altitude of Pittsburg, all observations by mercury column were reduced to a basis of approximately sea level conditions (barometer = 30") for purposes of ultimate comparison.

mercury column attached to the exhaust end of the turbine; temperatures of steam delivered to turbine, by thermometer immersed in oil cup at turbine throttle; superheat calculated from difference between observed temperature and temperature of saturated steam corresponding to the observed pressure; speed, measured by a reciprocating speed counter connected to the reciprocating governor motion which is geared to the turbine shaft; steam consumption determined by weighing the water of condensation from the condenser hot well by the alternate method at intervals of five or of ten minutes. As the load upon the turbine was maintained practically constant, the amount weighed during these intervals would also have been constant except for the following corrections:

(*a*) Condensed Leakage — determined immediately before and after regular test by closing all valves leading to the steam space of the condenser and placing the condenser under the same vacuum as obtained during tests. The amount of circulating water which then reached the condenser hot well represented the actual condenser leakage, which averaged about 5 pounds during an hour's test. (*b*) Gland Water used for sealing the packing glands at the two ends of the turbine casing was weighed at ten-minute intervals previous to its passage through the glands. As this water is finally drawn into the exhaust passages it was deducted from the total water condensed. (*c*) Height of Water in Hot Well — from the known dimensions of the condenser hot well, the weight of water per inch of depth was calculated. The difference in height at the beginning and ending of the test was noted and the equivalent weight allowed for in the final weight of steam.

These three corrections applied to the total weight of water at the end of the test gave the net weight of steam supplied to the turbine during each one-hour run; had the same corrections been applied at ten-minute intervals, these weights would have been approximately constant. How little variation actually occurred is shown on the accompanying log.

Log of Tests. — On Curve Sheet 3 will be found the complete observations made during the eleven tests given in Table II. Only such quantities have been plotted as might affect the economy of the turbine under the conditions of the test.

Generator Tests. For reasons previously stated, the turbo-generator was tested separately. Its characteristics are as follows:

Type: Turbo, revolving field, 3-phase, 2-pole.	
Excitation: separate	100 volt.
Rated full load capacity	400 K. W.
Full load current per terminal (100 per cent power factor)	527 amp.
Voltage, normal	440
Frequency (alternations per minute)	7200
Speed (revolutions per minute)	3600

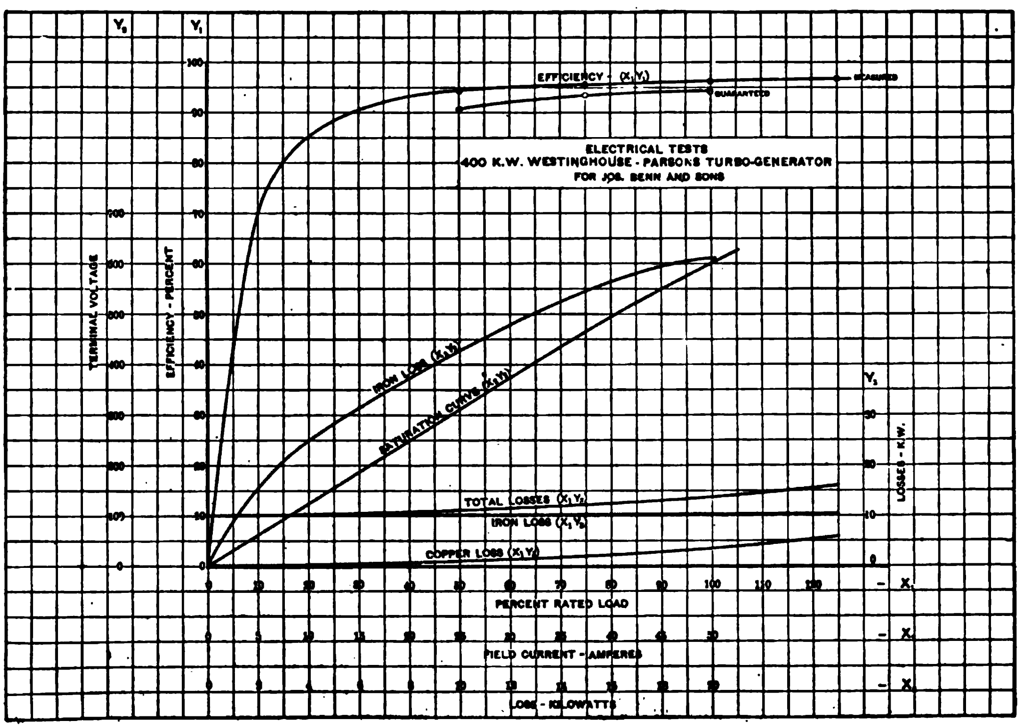
Methods of Testing Generator. — In general the same methods were employed as in the regular testing of engine-type generators of large capacity.

The measurements included:

(1) Iron loss in armature.
(2) Resistance of armature.
(3) Resistance of field.
(4) Saturation curve.
(5) Insulation tests.

From these data the efficiency is calculated. As the losses due to bearing friction and windage are small and are not easily segregated from other losses, they have been neglected.

Curve Sheet 4 shows the results of tests, together with the efficiency curves.



CURVE SHEET 4.

Efficiency of Generator. — Conforming with standard practice, efficiencies were based upon iron and copper losses, comprising:

(1) Hysteresis and eddy current losses in armature iron; determined by driving the generator at full speed, first fully excited and then without excitation. The difference in power consumption represents the total iron loss.

(2) C^2R loss in armature coils; determined from measured resistance of winding.

(3) C^2R loss in field coils; determined from voltage drop in windings; checked by separate resistance measurements.

Efficiency.	Guaranteed.	Measured.	Excess.
Full load	94.5%	96.6%	2.1%
¾ load	93.5	95.7	2.2
½ load	91.0	94.6	3.6

CHAPTER X.

THE following descriptive articles discuss the design of typical power plants. It will be noted that such points as could, in the opinion of the author, be bettered are criticised. Each of the five plants have their own particular features upon which special stress has been laid: as, for instance, the St. Denis plant, Paris, with its unique unit system and labor-saving devices; the Chelsea plant, London, having a typical two-tier boiler house, and well-arranged turbine room; the 59th Street plant, New York, being the largest plant at present in operation and having the largest reciprocating engine in the world; and the Fisk Street plant, Chicago, a plant typical of the class having the boiler and generating rooms at 90°, a system which has since been frequently adopted. The Vienna plant represents typical Continental practice, and as will be seen throughout the discussion is laid out to reduce the operating cost to the minimum.

ST. DENIS PLANT, PARIS.

On account of its departure from usual practice, a notable plant still under construction is the St. Denis plant of the Société d'Electricité de Paris. This plant is not only notable for being the largest power plant in Europe, or the largest Parsons turbine plant in the world, but on account of the number of separate buildings, the unique arrangement of the unit system and the many novel features employed throughout the equipment. One of the principal endeavors in designing the plant was the reduction of the labor to a minimum; automatic apparatus being employed as much as possible. As will be seen in the following discussion, the number of employees is extremely small for a plant of this capacity. Although, as will be pointed out, there are items to be criticised, the plant is on the whole exceptionally well designed, and serves as an example of most modern engineering.

This plant, which is located directly on the Seine, has been built to supply the city of Paris and its suburbs with light and power, to assist two already established companies, and to supply current for the Metropolitan Subway, which is the largest consumer. Besides the above services, there are trolley lines near the plant supplied with 580 volts direct current. Owing to the different character of the service required by these consumers, two entirely separate and distinct systems are installed, viz., 3-phase, 25-cycle, 10,250-volt, and 2-phase, 42-cycle, 12,500 volt. The total normal capacity of this plant amounts to 60,000 K.W., three-quarters of which is 3-phase and one-quarter 2-phase.

Layout. — Fig. 2 gives the general arrangement of the plant. It will be noticed that there are three separate boiler rooms running at right angles to one turbo-gen-

FIG. 1. Exterior of St. Denis Plant, Paris.

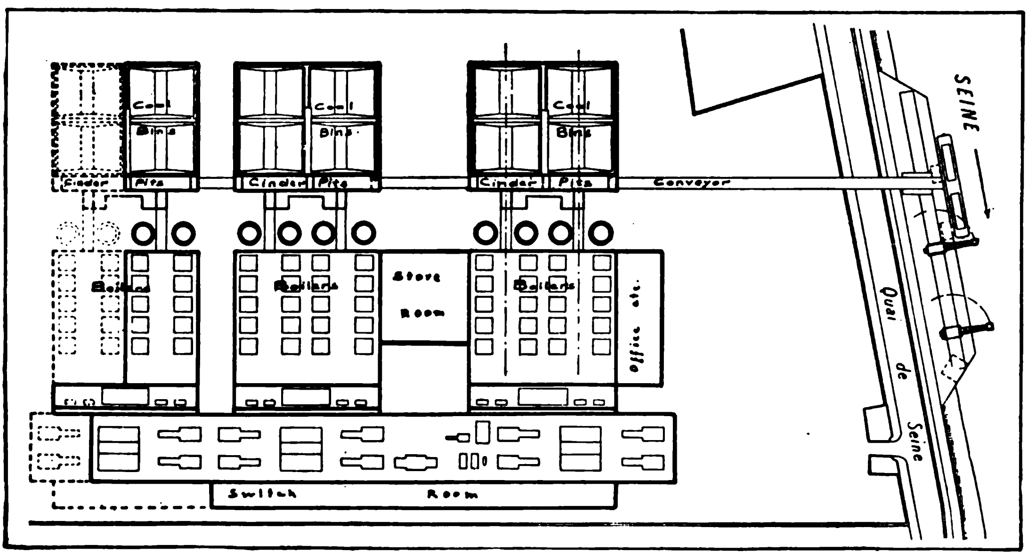


FIG. 2. Plan of St. Denis Plant, Paris.

erator room, while on the opposite side of the generator room is an annex containing the switching rooms. In the rear of the boiler rooms are 12 chimneys and three sepa-

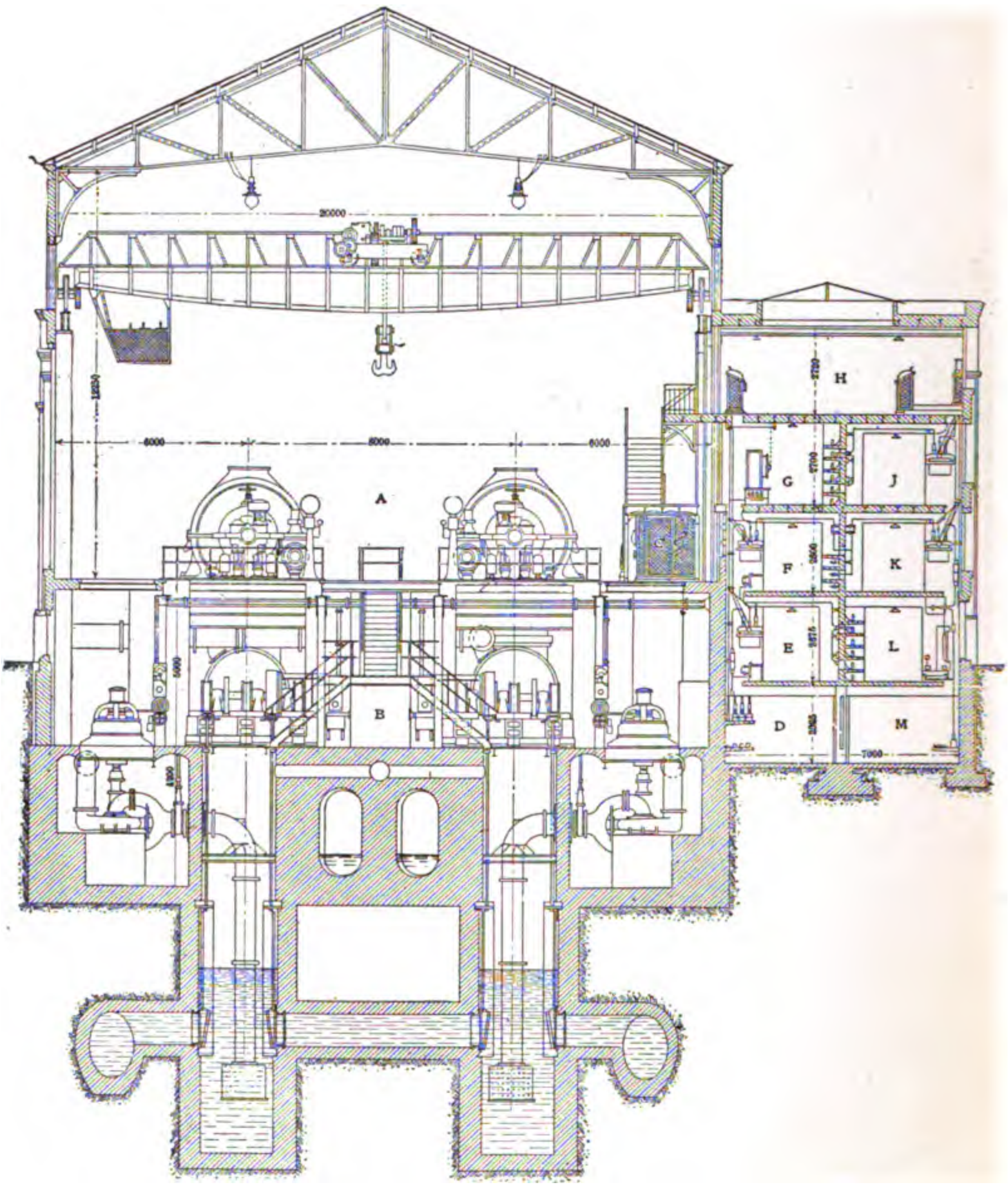


FIG. 3. Cross-Section, St. Denis Plant, Paris.

rate coal and ash buildings. Separate feed-water rooms are located between the generator and boiler rooms. At the right-hand end of the boiler plant is a building used for offices, canteen, baths, etc., while between the two boiler rooms farthest apart is a large storage building.

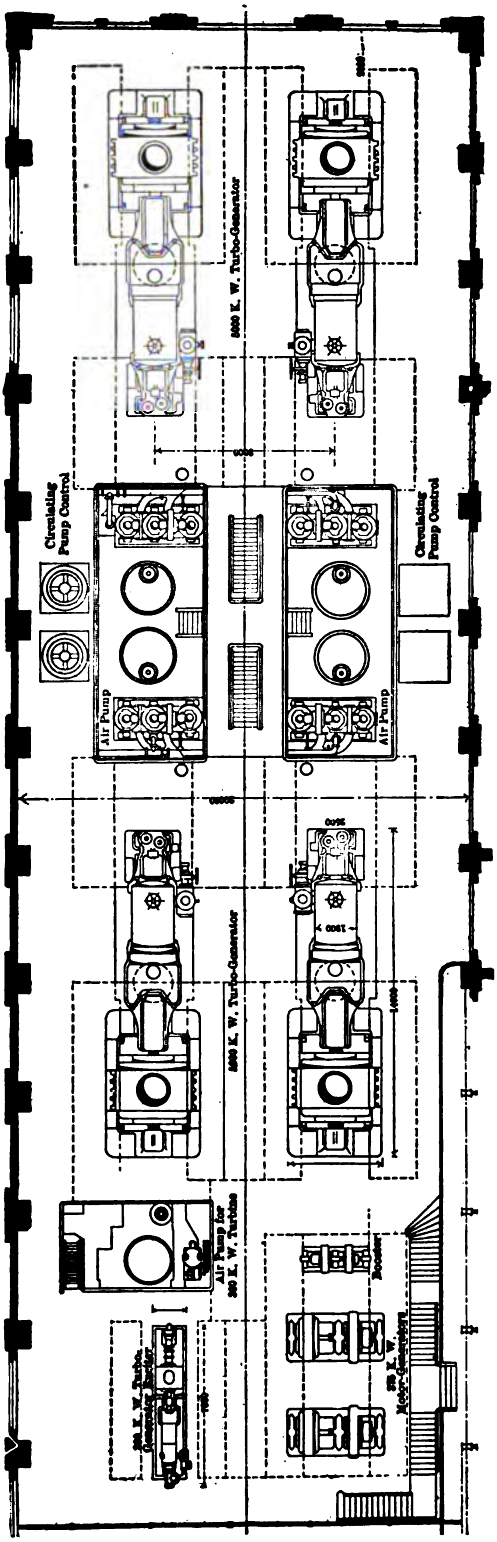


FIG. 4. Turbo-Generator Room, St. Denis Plant, Paris (showing one-third of the ultimate equipment).

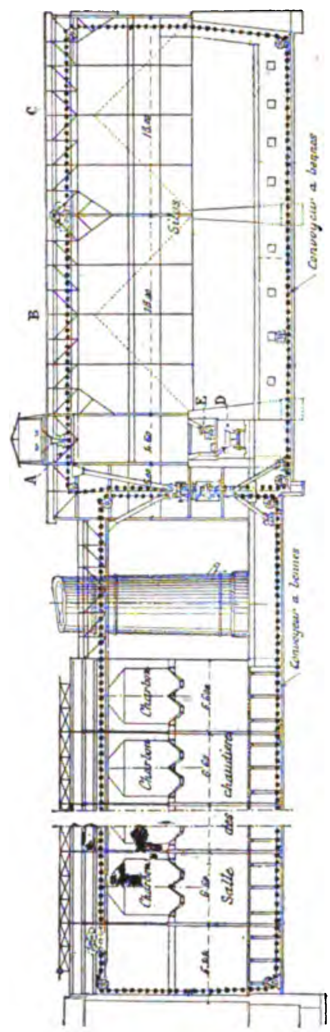


FIG. 5. Coal and Ash Handling System, St. Denis Plant, Paris.

All coal is brought in from barges on the Seine, unloaded by a locomotive crane, and conveyed to the storage buildings.

The generator room is designed to accommodate twelve 5,000-K.W. turbo-generators, with the condensers and auxiliary machinery located in the basement some 16.5 feet below; this building is 656 feet long by 65.5 feet wide. The boiler rooms are square buildings, each 140 feet by 140 feet, provided with basement 9.75 feet high, with an economizer floor 20.5 feet above the boiler-room floor. The boilers are of the marine type and arranged in 4 rows of 5 boilers each, with a heating surface of 4,500 square feet. As there are three buildings the total number of boilers is sixty.

Between the economizers and above the firing aisle are suspended coal bunkers with a capacity of 40 tons per boiler. Between the boiler and generating rooms are rooms extending the full width of the boiler room and 19 feet 6 inches wide, used for boiler feed purposes. Here are installed purifiers, pumps, storage tanks, etc. The coal and ash buildings are also 140 feet square, and each building is divided into 4 coal bins with a capacity of 4,000 tons. Between each boiler house and coal storage bin are four chimneys, making a total of twelve.

It will be noticed that the entire plant is spread over a great area, wasting a great amount of land; as, for instance, the space between the boiler rooms. Considering, however, the space occupied by the individual boiler rooms and generator room, the layout is very compact, and as will be seen in the accompanying illustration of the generator room, the turbines are laid out so as to give more than ample room around the units. The following figures show the space occupied per K.W. of the boiler, generator and switching rooms; the coal storage buildings are not considered, as it would not be justifiable to consider same.

Boiler room	1.12 Sq. Ft. per K.W.
Generator room	.70 " "
Switching room	.26 " "
Total	2.08 " "

Including the total area of the rectangle occupied by the plant, including the chimneys, but not the coal bins, a ground space 2.89 feet per K.W. is the result.

The plant is divided up into a unit system. Each four turbo-generator unit is supplied by one boiler plant, with four chimneys and one coal storage building. This gross unit may be subdivided so that one turbo-generator, having its own condenser plant, is supplied by one row of five boilers with chimney and one coal storage bin. The first gross unit has been in operation since 1906, the second gross unit being finished at the end of 1907, and the third unit will soon follow, completing the plant. Should necessity arise this plant may be easily extended on account of this particular arrangement of the unit system.

Coal and Ash Handling Systems.—The coal is brought in barges on the Seine and unloaded by two electrically operated locomotive cranes. The coal is lifted by grab-buckets, crushed, automatically weighed and elevated by bucket conveyors to the

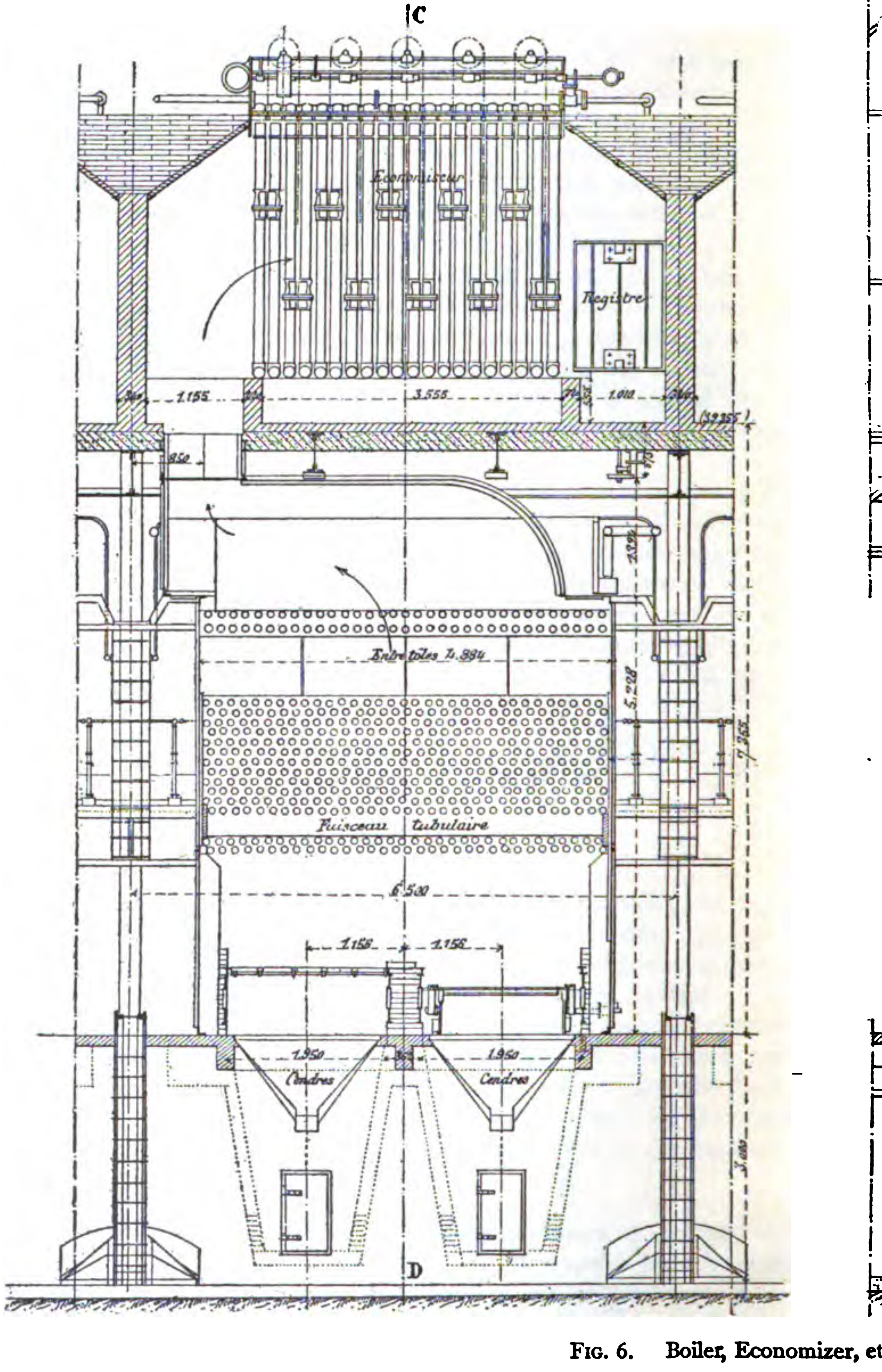
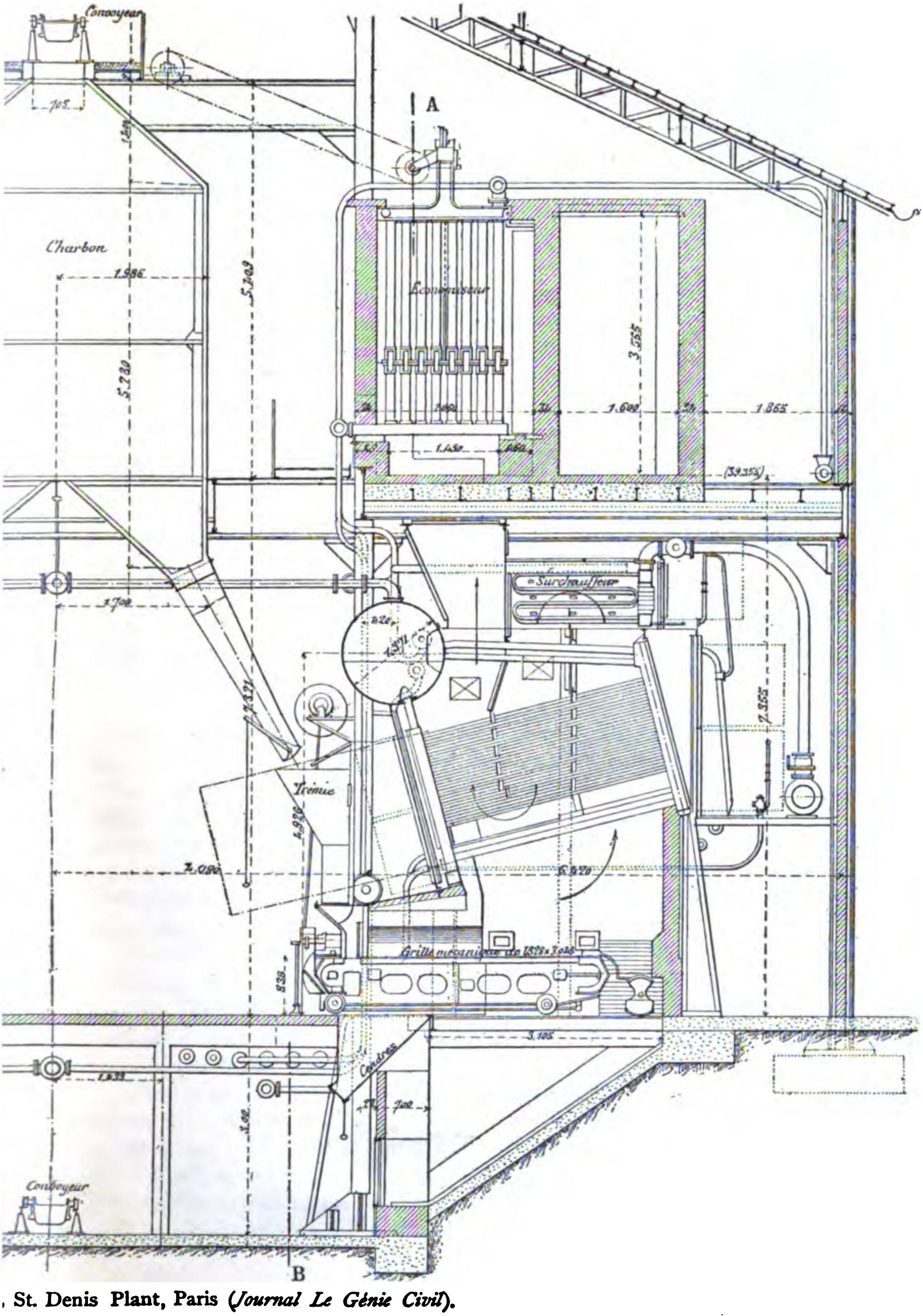


Fig. 6. Boiler, Economizer, et



, St. Denis Plant, Paris (*Journal Le Génie Civil*).

storage bins, or it may be transferred directly to the bunkers in the boiler room. The coal from the storage bins may be automatically reclaimed, as will be seen in the accompanying illustration, weighed and conveyed, also by means of bucket conveyors, to the suspended bunkers in the boiler rooms. The fine coal falling through the boiler chain grates is reclaimed and conveyed back to the suspended bunkers. The ashes are conveyed in a similar way and elevated into the ash pit in the front of the coal storage buildings, whence they may be dumped into carts and drawn away or conveyed to the barges at the river.

There are installed two locomotive cranes and two main conveyors to the various buildings, two conveyors in each coal storage building and two conveyors for each boiler house (one for each firing aisle). All these conveyor mechanisms are electrically operated.

The locomotive cranes and the main conveyors are each designed to handle from 40 to 50 tons of coal per hour. Each storage building has a capacity of 16,000 tons and is divided into 4 equal bins. The suspended coal bunkers in the boiler room are made up of rolled steel, each having a capacity of 80 tons per two opposite boilers. It must be noted that these bunkers are not continuous, but each two boilers have their own individual bunker, 14.5 feet long. This design is complicated and increases the first cost, while the coal storage capacity is materially cut down. These disadvantages outweigh the one redeeming feature, increased light and ventilation. From each bunker two conical down-takes lead to each boiler. There is a separate down-take at the end of the boiler room leading vertically to the center of the firing aisle, from which coal may be taken to any of the boilers in case of emergency.

Boiler Room. — As has already been pointed out, each boiler room contains 20 boilers in four rows, thus giving two firing aisles. The boilers are of the Babcock & Wilcox marine type, separately set. The heating surface of 4,500 square feet per boiler is made up of one 52-inch drum, 15.75 feet long, and 33 sections of 14 tubes each, 10 feet long and 3¼ inches diameter. The floor space occupied by each boiler is 267 square feet. Each boiler is provided with two chain grate stokers, the combined grate surface being 70 square feet. One row of 10 grates is operated from one 10-horse-power motor.

Directly above each boiler is installed a superheater of 640 square feet capable of furnishing 680° Fahr. superheat at 175 pounds, as has been proven by test. As, however, the turbines are designed for a total temperature of 570° or 200° Fahr. superheat, provision is made to regulate the temperature. Some 20.5 feet above the boiler-room floor is located the economizer floor.

There is installed for each boiler one economizer, having a heating surface of 1,720 square feet. The scrapers of one row of economizers (5) are operated by a 15-horse-power motor. The total height of the boiler house from basement to roof peak is 65 feet. It will be seen that the entire structure has been kept extremely low, and in fact it is impossible to walk on the top of the boilers to make repairs, etc., while, on the other hand, much space is wasted in the other direction, the firing aisles being 27 feet wide.

Superheaters and economizers may be easily by-passed, the smoke passing directly to the chimneys. The latter are 165 feet above the fire grates and have a diameter at the top of 10 feet. Each row of five boilers has one chimney.

Feed-Water Plant. — A separate feed-water plant for each gross unit is located between the generator rooms and the boiler room. It contains 3 triplex double-acting pumps, operated by 80 horse-power motors, and 1 centrifugal pump operated by a 100-horse-power motor. Each pump has an hourly capacity of 1,980 gallons (U.S.)

FIG. 7. Interior of Boiler Room, St. Denis Plant, Paris (*Electrical Review*).

or 1,650 gallons (British). Besides the water-storage tanks, each plant contains two water-purifying systems, each having an hourly capacity of 185 gallons (U.S.) or 145 gallons (British). The extremely small capacity of these purifiers is accounted for by the fact that the water of condensation is returned to the boilers and this purifier plant is used only for the make-up water, for losses, etc., which is drawn from the river Seine.

From this feed-water plant the supply for the entire twenty boilers is controlled by one attendant. Although these boilers are equipped with water columns, magnetic mechanical indicators are installed, which indicate the water levels in the various boilers. It will be seen that by this system uniformity in the water supply, as well as a material saving in labor, is effected.

Turbo-Generators. — The turbo-generators are of the Brown-Boveri-Parsons type, each having a normal capacity of 5,000 K.W., with a maximum overload capacity of 20 per cent. The entire generating room has been designed for twelve such units; the author, however, understands that in the near future larger turbines will be installed. These turbines are designed for a steam pressure of 175 pounds and superheat of 575° Fahr., and are under a vacuum of not less than 27 inches; the guaranteed steam consumption per K.W.-hour is 14.7 pounds. They are direct-connected to the generators, but are not mounted on a common bedplate. The generator and the bearings on

FIG. 8. Interior of Generating Room, St. Denis Plant, Paris.

each side are bolted to one bedplate, while the bearing at the high-pressure side of the turbine has a separate bedplate, the space between the plates being 18.5 feet. The turbine casing is suspended between these two bearings, and provision is made to allow the outside bearing to slide on the bedplate in order to take up the expansion and contraction. The turbines rest on boxgirders, the deepest of which is 26 inches, and in order to reduce the resonance of these girders the space between same is filled with concrete.

As previously stated the generators are 500-K.W. capacity and run at 750 R.P.M. 3-phase, 25 cycles, 10,250 volt and 2-phase, 42 cycles, 12,500 volt. The over-all dimensions of the turbo-generator unit are 47 feet 9 inches long and 15 feet 7 inches

wide, while the highest point of the turbo-generator is 11 feet 6 inches above the floor level. It may be of interest to mention the rapidity with which these units were installed. One of these 5,000-K.W. units arrived at the power house on a Saturday evening and eight working days later was in operation.

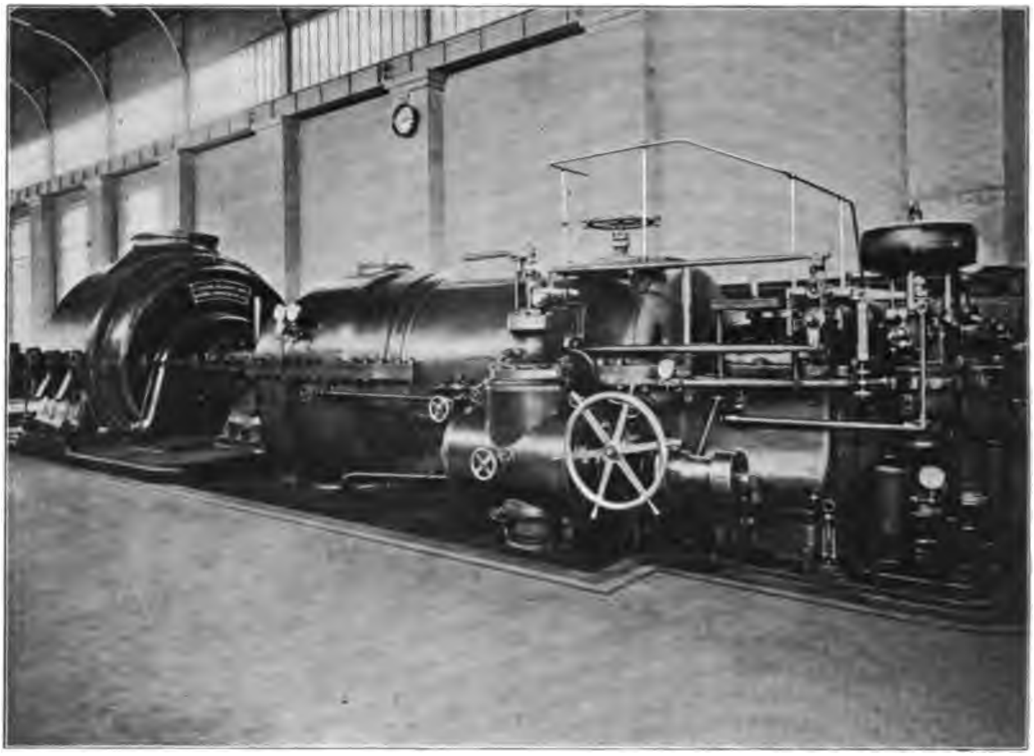


FIG. 9. 5000-K.W. Brown-Boveri-Parsons Turbo-Generator, St. Denis Plant, Paris.

Condenser Plant. — The entire condenser plant is located in the basement, as will be seen in the accompanying illustration. The four turbines in one gross unit are arranged in two rows with the steam ends facing each other, thus allowing the four condensers to be symmetrically arranged together in the basement, with an opening in the main operating-room floor, giving an unobstructed view of the entire condenser plant. The circulating water is taken from the Seine and two separate intake and discharge tunnels are provided, thus giving a very symmetrical arrangement but expensive system. On both sides of the intake tunnels are provided suction wells some 60 feet deep and 6 feet in diameter. These wells are interconnected by a conduit. As will be seen in the cross-section, the flow from the intake tunnels to the suction wells is provided with sluice gates operated from the condenser or basement floor. The discharge, as will be noted, is located in the center of the plant just below the basement.

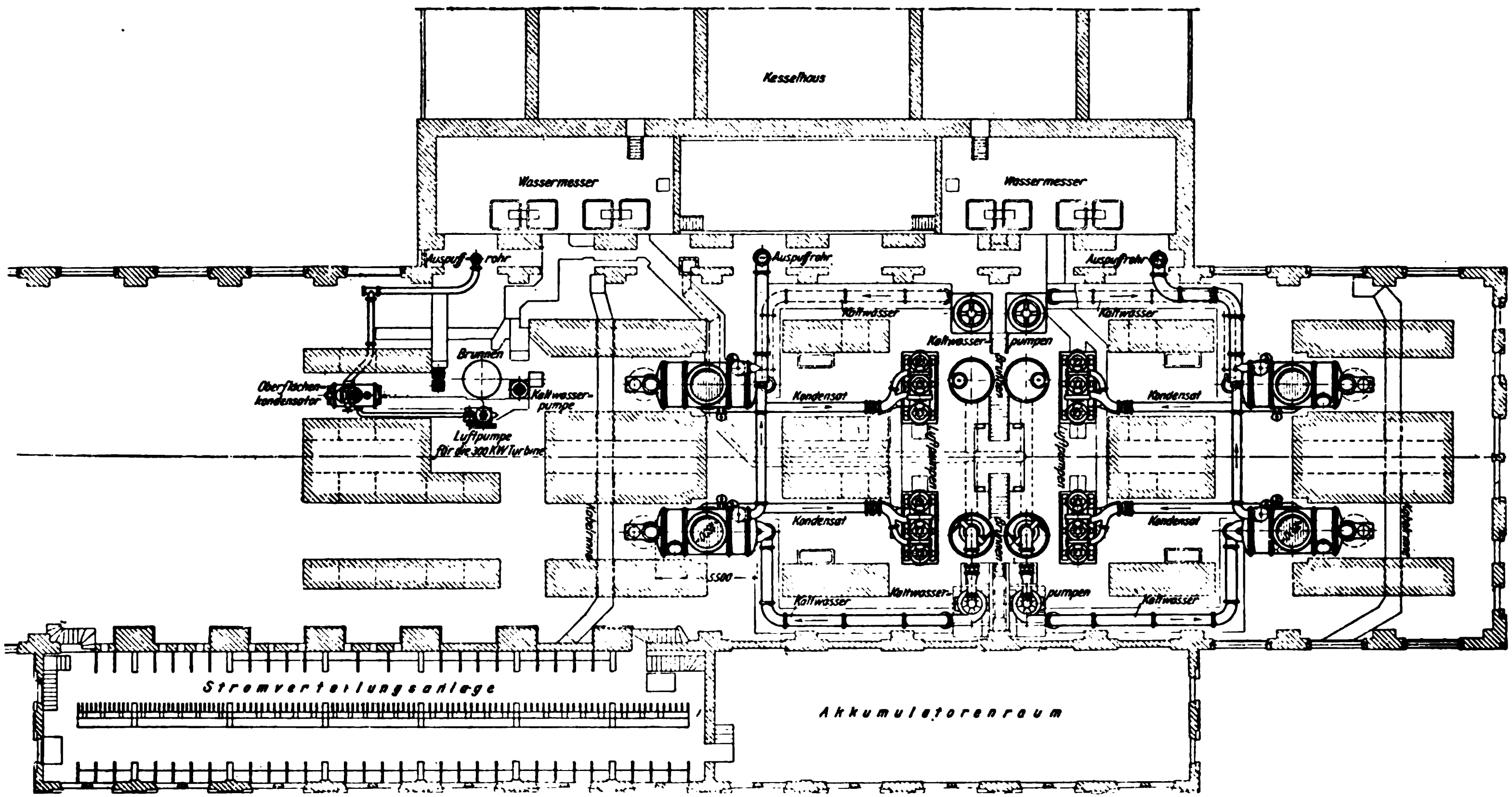


FIG. 10. Condenser Plant, St. Denis Plant, Paris (*Zeitschrift des Vereines deutscher Ingenieure*).

Each turbine is provided with its own condenser plant, the condenser itself being located directly below the exhaust outlet, the connecting flanges being water-sealed to preserve a high vacuum. On account of the above-mentioned provision made for the expansion of the turbine, one end of the condenser is placed on rolls. Owing to the high lift of the cooling water, the circulating pumps, which are of the double suction centrifugal type, had to be placed in the sub-basement. The vertical motors operating these pumps are located on the main condenser floor and are of 150-horse-

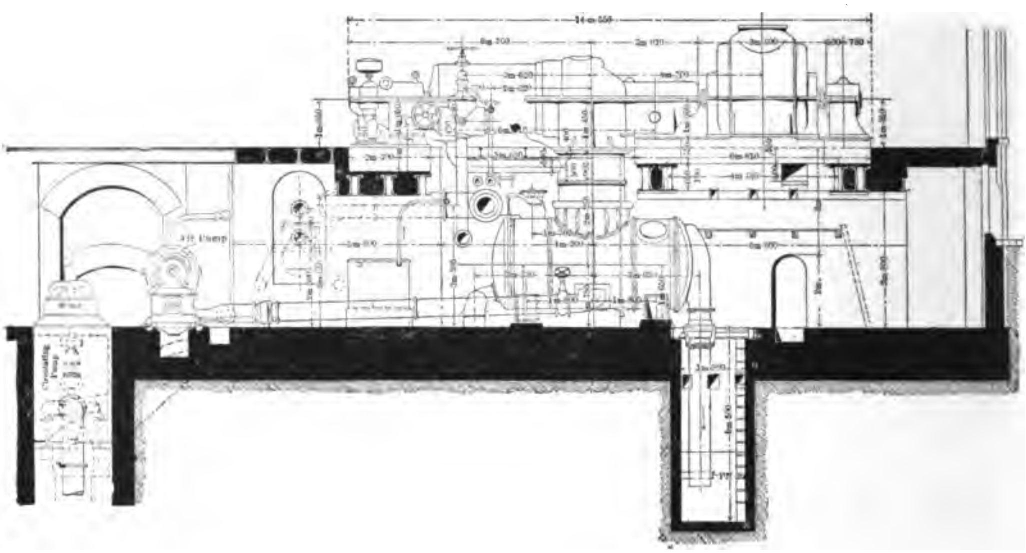


FIG. 11. Side Elevation of a Turbine Unit, St. Denis Plant, Paris.

power capacity each. The air pumps are of the three-cylinder, single-acting type and are operated by 50-horse-power horizontal motors.

Auxiliary Electrical Equipment. — As the entire auxiliary apparatus of the plant is electrically driven, the electrical equipment is a most complete one.

The exciter plant consists of one 300-K.W. 220-volt turbo-generator provided with its own condenser equipment, consisting of surface condenser, a 16.5-horse-power circulating pump and a 9-horse-power air pump.

There are two 375-K.W. motor generator sets for supplying direct current for the various motors, exciting the alternators, operating the condensers and boiler feed pumps, coal and ash conveyors and for lighting purposes, etc. The motors are operated on 3-phase, 10,250 volt, 25 cycles, and the dynamos generate current at 220 volts. Besides this there is also a 110-horse-power booster set for charging a 126-cell battery with a capacity of 1,300 ampere one-hour discharge rate.

A very interesting and unique feature of this plant is the "polymorphic" group, a machine made up by assembling four different machines on a single shaft, as shown in the illustration. This group is made up of two motors and two generators. At

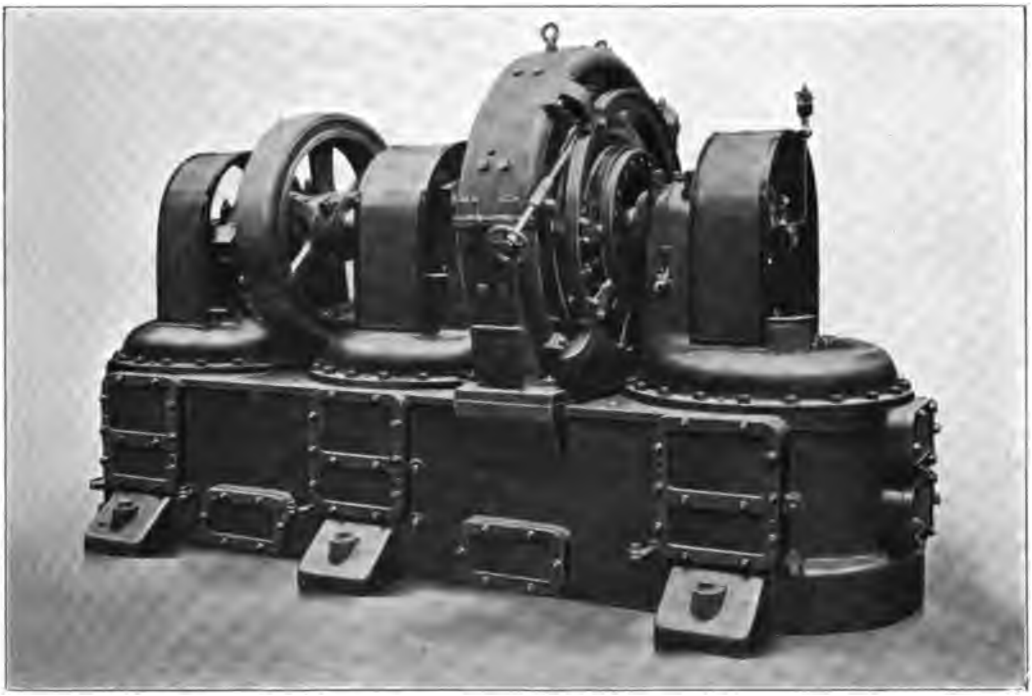


FIG. 12. 50-H.P. Motor-Driven Wet Air Pump, St. Denis Plant, Paris (*Power*).

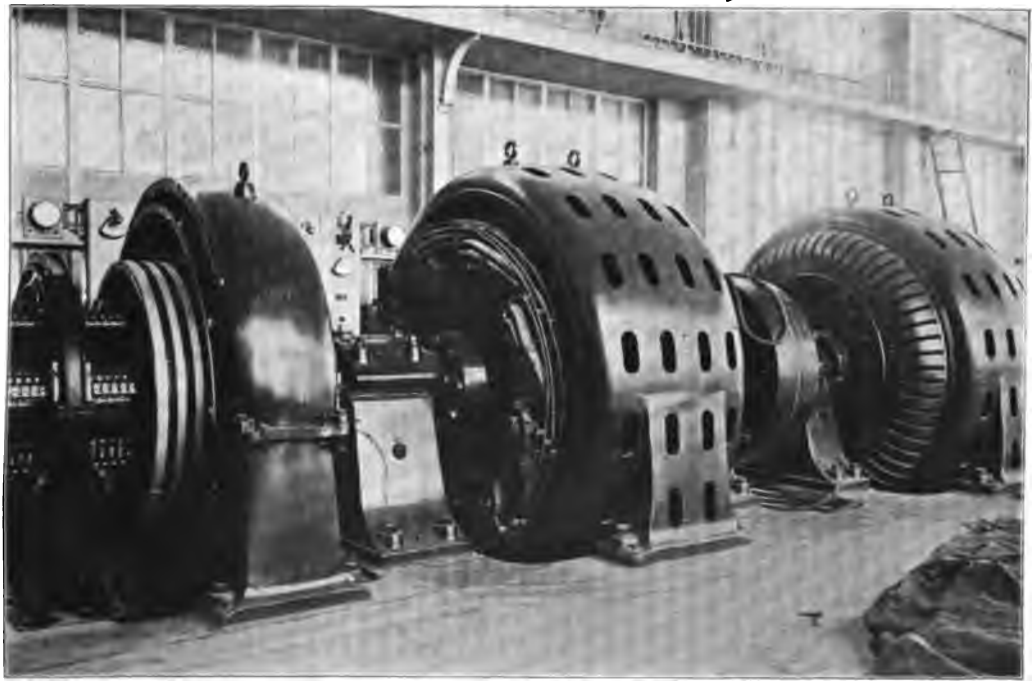


FIG. 13. Polymorphic Set, St. Denis Plant, Paris (*Electrical Review*).

each end of the shaft is one 550-volt direct-current generator, between which is one 3-phase, 25-cycle, 10,250-volt alternator, and one 2-phase, 42-cycle, 12,300-volt alternator, the latter being also arranged to give 6,150 volts. In the middle of the group is an electrically operated mechanical clutch coupling, making it possible to use the group in two sets or, if required, the two alternators, each having a capacity of 750 K.W., may operate together under a load of 1,500 K.W. on the 550-volt service. It is also possible with this group to balance the load on the two altermator systems by running either the 25-cycle or the 42-cycle machines or a motor.

Switching Room. — By studying the cross-section of the switching rooms it will be noticed that the various types of apparatus are kept in separate rooms. Starting in

FIG. 14. Switch and Controlling Benches, St. Denis Plant, Paris.

compartment "D," which contains the generator leads, the current flows in alphabetical order from one compartment to the other, the apparatus being located as follows: "E," main generator switches; "F," the main bus-bars; "G," rheostats; "H," taking the entire upper floor, contains the controlling bench boards and the low-tension switchboards. No high-tension current gets into the upper compartment, but is carried across to compartment "J," where are located the feeder switches. Compartment "K" contains the bus-bar junction switches, while "L" contains the potential regulators. The last compartment, "M," serves for the outgoing cables. There is also another small switchboard on the main generating-room floor shown in the cross-section "C," and more clearly illustrated in interior view of the generating room.

This board is located directly beneath the stairs leading to the main controlling floor, and contains the switches and instruments required for the control of the exciter unit, motor generator sets, booster, polymorphic group, etc.

All oil switches are hand operated through connecting rods, from the main controlling floor. While the bus-bars are not placed in compartments, they are separated by means of horizontal shelves left open at the front, and are supported on triple petticoat porcelain insulators carried on cast-iron brackets.

Operating Force. — As already pointed out in the beginning of the discussion, special attention has been given to the reduction of the operating force of the plant, and the following list shows with what result. This list refers to one gross unit consisting of one boiler plant of 20 boilers, 4 turbo-generators, 20,000 K.W., with all electrical and mechanical auxiliaries necessary to make a complete plant.

1 Superintendent.
1 Engine tender.
1 Helper.
2 Electricians.
1 Fireman.
2 Helpers.
1 Feed-water tender.
1 Helper.
2 Ash tenders.
2 Conveyor tenders.

The day is divided into three shifts, and during the daytime, when coal has to be unloaded, repairs made, etc., there is an additional force of three, viz.:

1 Crane man.
1 Master machinist.
1 Machinist.

When the plant is completed, with three gross units (60,000 K.W.), the above force will not be proportionately increased, but will be smaller.

Not including the output of auxiliary machinery and figuring the plant at normal rated capacity, when the greatest number of men are employed, there will be only one man for each 1,200 K.W., while in other shifts there is one man for each 1,500 K.W.

FIFTY-NINTH STREET PLANT, NEW YORK.

For operating the Subway System of New York City a power plant has been erected between 58th Street, 59th Street and 11th Avenue and the Hudson River. This plant is one of the largest steam-electric power plants in the United States, and, although it possesses but few novel features, it is prominent because of its capacity.

The station is 693 feet 9 inches long and 200 feet 10 inches wide, while a space of 250 feet is left to the river bank, part of which may be built upon at some future date

for an extension. The boiler room is separated from the generating room by means of a division wall; the room runs the entire length of the plant and is 83 feet 1 inch wide, while the generating room is 117 feet 9 inches wide, including the 23 feet space for switching room, and 18 feet for the so-called pipe gallery.

The boiler room contains a basement 14 feet 6 inches high, one boiler floor 37 feet high, one economizer floor and a coal bunker, the top of which is 93 feet above the basement floor. The coal conveyors are 5 feet above the top of the bunkers. The peak of the roof is 122 feet 9 inches above the basement floor. The basement of the

FIG. 1. 59th St. Plant, New York.

engine room, which is flush with that of the boiler room, is 22 feet 6 inches high, while the pipe gallery is 15 feet 6 inches above the generating-room floor. Opposite to the pipe gallery is the switching room, which contains in the basement a gallery 13 feet 6 inches above the basement floor, while the switchboard gallery is 29 feet above the generating-room floor. The top of the crane runway is 64 feet 7 inches above the engine-room floor. The peak of the roof is 123 feet 9 inches.

The steel work used in this building is self-supporting, and all floor beams, etc., are carried as much as possible upon the steel work, instead of on the building walls. Some 12,300 tons of structural steel has been used. The walls are of red brick of extra good

quality, faced with gray tile, harmonizing with the terra cotta so prominently used. The style of the building is supposedly French renaissance. A great deal of granite has been used up to the water table and for framing doors and windows. The roof is constructed of hollow fireproof tiles, covered with dark green Spanish tile. Considering the price of the structure, which amounted to $1,933,000 (including structural steel), it does not appear, architecturally, as handsome as it might. Besides the fine ornamental work with which the three main walls are decorated, it does not harmonize with the five naked prominent stacks. If the walls had been designed without any terra cotta, of heavy massive pilasters and prominent windows, the whole plant would have a more impressive and powerful appearance, designating the character of the plant, which is a feature that should not be lost sight of in the design of large plants.

The layout of the plant is designed on the unit system, each two prime movers having their own two complete condenser plants, 12 boilers (6 batteries), two boiler-feed pumps, four economizers and one chimney. The ultimate normal capacity for which the plant has been designed is 90,000 horse-power.

Circulating Water System.—Condenser water is drawn directly from the Hudson River. The intake and outlet tunnels, the latter above the former as shown in cross-section, are run beneath the sidewalk of 58th Street and along practically the entire length of the building. The reason the tunnels were located on 58th Street was that the original intention was to locate the condensers in the center of the plant between the generator room and the boiler room in the pipe area, beneath which the circulating pumps are located.

The intake tunnel has an area of 82 square feet, while the area of the outlet is 70 square feet. Both tunnels are made of concrete and rest at the river end on piles. This latter section, some 65 feet long, was built in a floating caisson and sunk 19 feet 6 inches below mean high-water mark, resting on the aforementioned piles, which had been cut off at this depth. In order that the discharge water will not flow directly back into the intake, the outlet tunnel has been extended 40 feet into the river beyond the intake. This latter section is a wooden flume, supported from the dock. The intake is provided with a rough and fine screen.

Coal and Ash Handling Systems.—On the above-mentioned dock there are two coal-hoisting towers. One of these towers is movable and has a capacity of 200 tons per hour; it is provided with a 1½-ton grab-bucket and is operated by steam. The other tower is fixed and is electrically driven, having a capacity of 150 tons per hour. The grab-bucket is of one-ton capacity.

The coal is crushed, weighed and delivered on a 30-inch motor-driven belt conveyor to the foot of 58th Street, thence it is transferred to another conveyor located in a tunnel at the side of the water intake tunnel leading to the end wall of the power house. From here the coal is picked up by another belt conveyor. As these conveyors will not run at an angle greater than 23°, it was necessary to install four of them

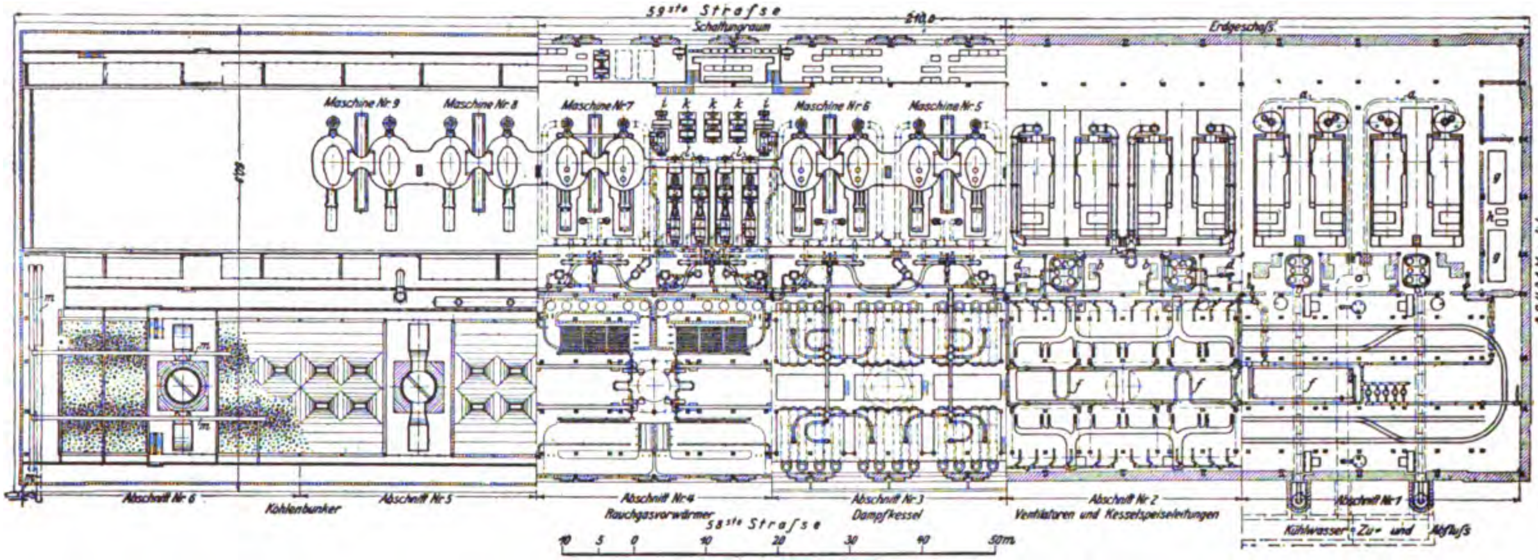


FIG. 2. Plan of 59th St. Power Plant, New York, showing Equipment at Various Elevations (*Verein deutscher Ingenieure*).

a. Hot Well Discharge
b. Air Pumps
c. Circulating Pumps
d. Boiler Feed Pumps
e. Blowers
f. Water Storage Tanks
g. Oil Filtering Tanks
h. Oil Pumps
i. Exciter Engines
k. Motor Generators
l. Turbo-Generators
m. Coal Conveyors

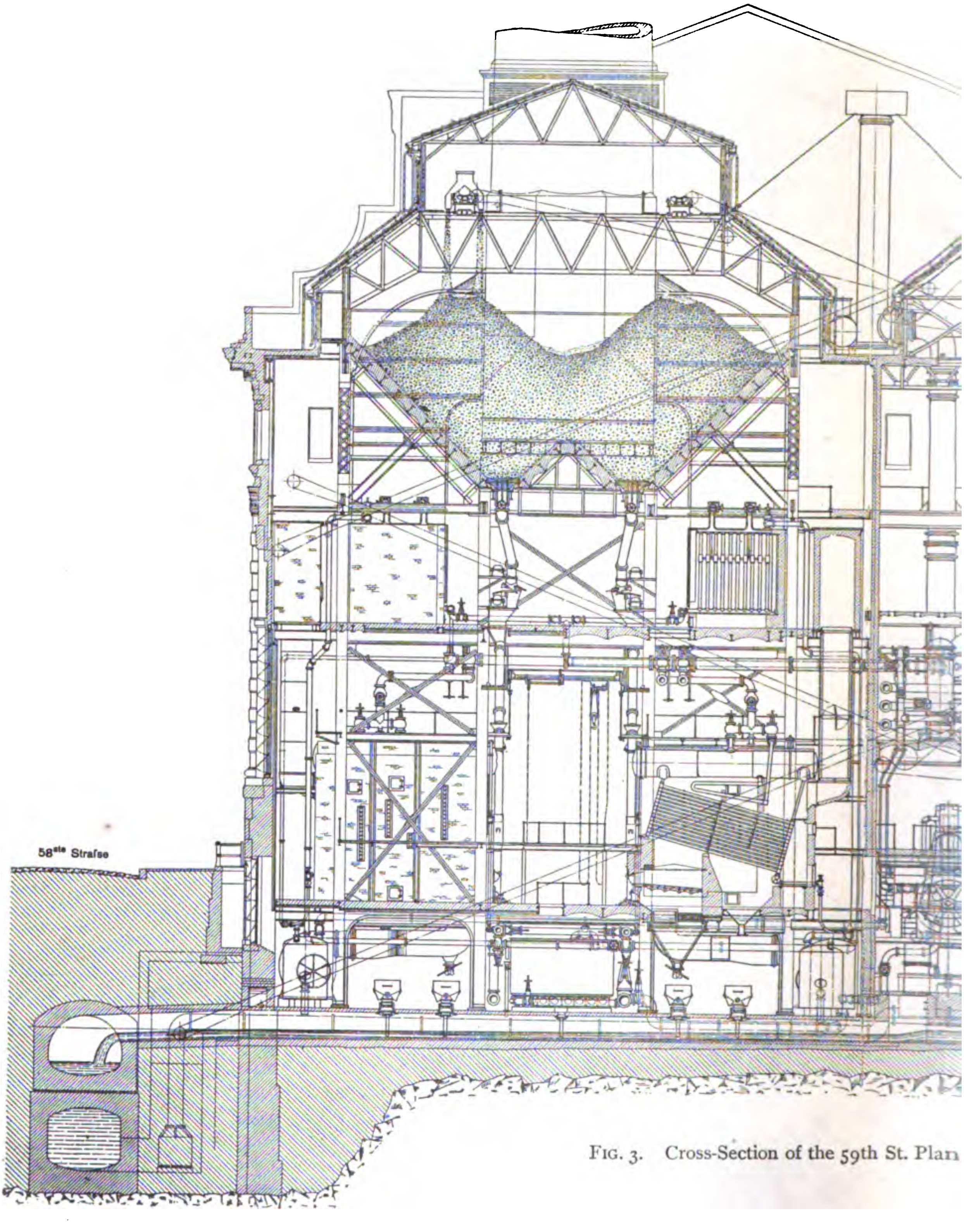
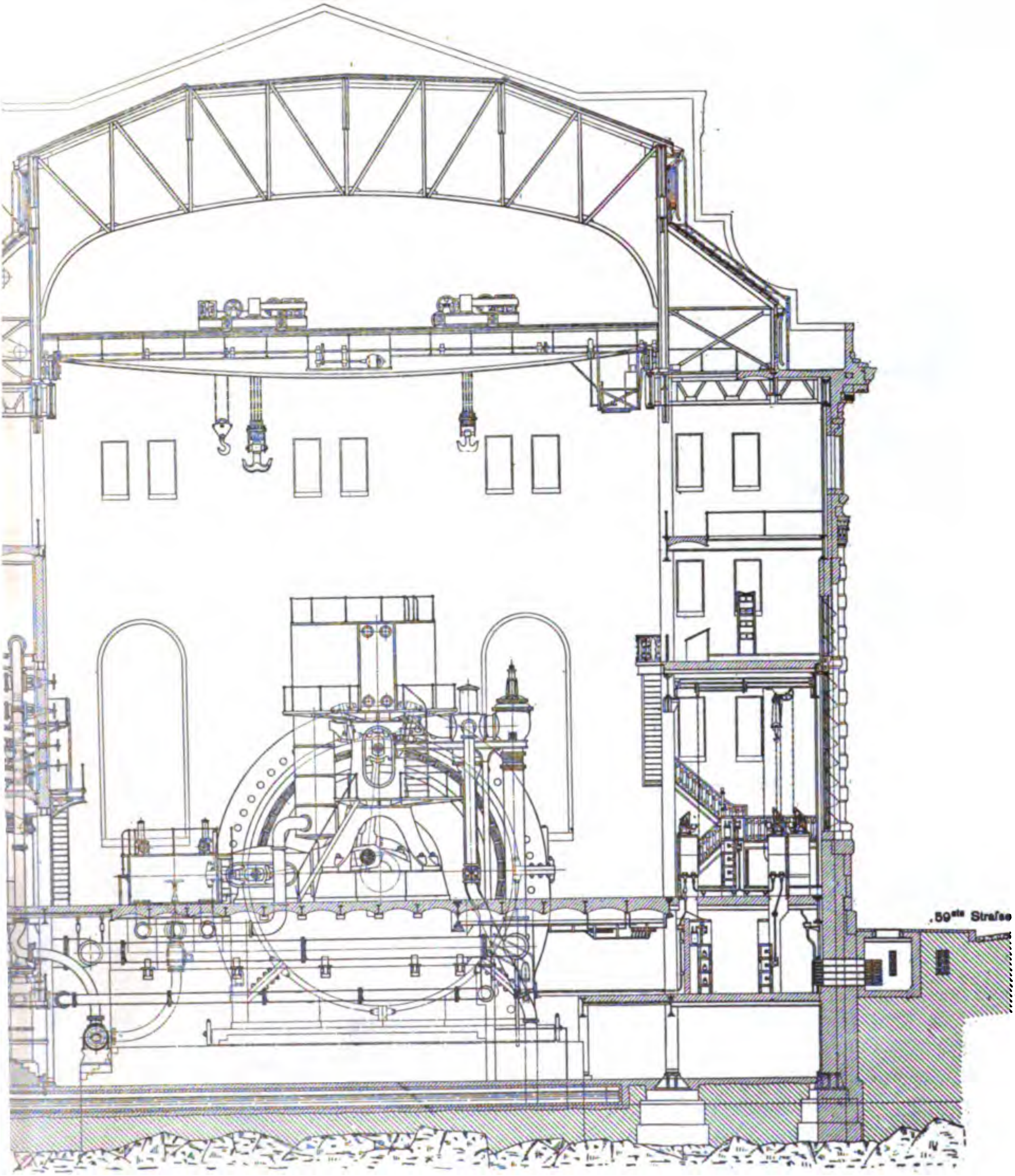


FIG. 3. Cross-Section of the 59th St. Plan



, New York (*Zeitschrift des Vereines deutscher Ingenieure*).

to bring the coal to the top of the bunkers. After reaching the top of the bunkers the coal is unloaded on one of the two 20-inch longitudinal conveyors for distribution over the bunkers. Due to the considerable length of these latter conveyors, the power house being 693 feet long, they had to be divided in two. The total carrying distance of these belt conveyors is 1,450 feet.

It will be seen that this arrangement of coal conveying is a very cumbersome one, belt conveyors being hardly adaptable for elevating coal some 110 feet in such a narrow space. Besides it is necessary to install a great number of motors, and if one of these,

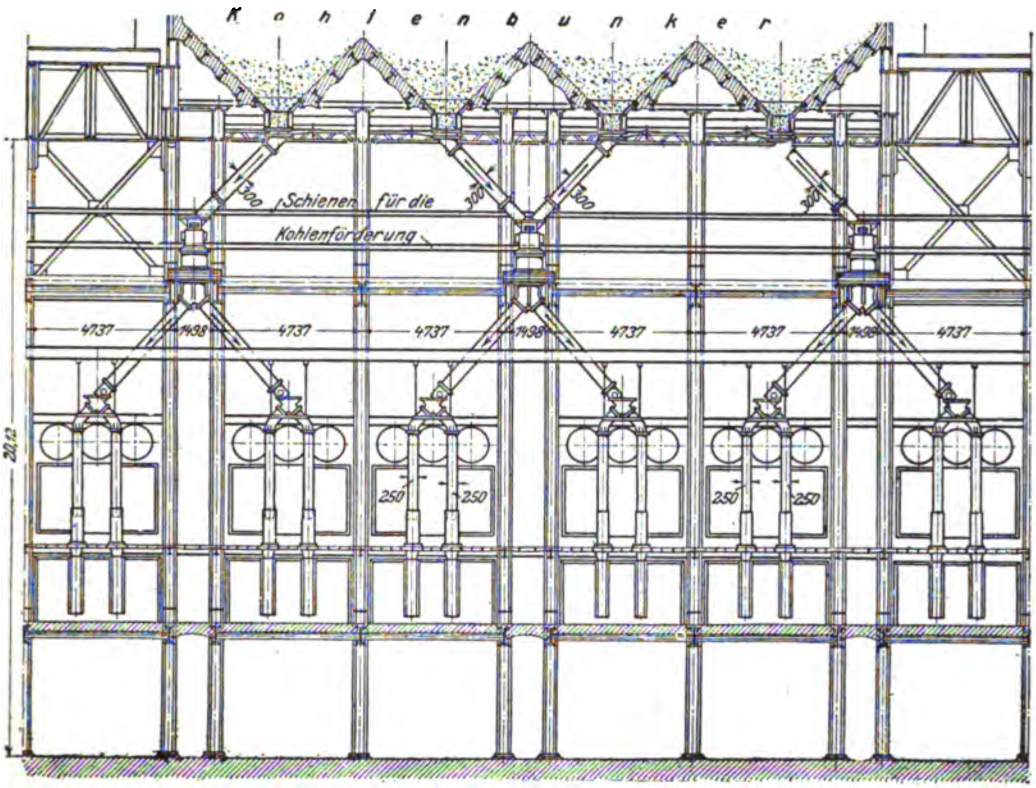


FIG. 4. Coal Down-Takes, 59th St. Plant, New York (*Zeitschrift des Vereines deutscher Ingenieure*).

or should one of the belts, break down, the entire system would be paralyzed, which is doubly serious, for the system is not in duplicate. Of course, the coal bunkers, of which there are seven, having a total capacity of 15,000 tons, would run the plant for a considerable length of time. Another disadvantage of this system is the fact that should the building be extended, a possibility which might easily arise in New York, due to its railway conditions, the entire elevating system would have to be renewed.

On the economizer floor there are installed two motor-driven scraper conveyor systems. These conveyors had also to be divided into two sections because of their

length. These conveyors have been installed for the purpose of distributing coal from any bunker to any boiler. Coals of different grades may be stored in different bunkers, so with this system, where the load is light, a low grade of coal may be burned in the boilers and *vice versa.*

The coal down-takes from the main bunkers to the scraper conveyors are 14 inches in diameter, while from the receiving hopper of the conveyor to the top of the boiler the down-take is also 14 inches, dividing at the top of the boiler into two 10-inch pipes.

The boilers are provided with plate steel ash hoppers, lined with hollow tile. The soot hoppers in the rear of the boilers are of cast iron. Ashes are removed by a narrow-gauge railway system located beneath each row of boilers. The ashes are drawn to the water edge by a storage battery locomotive to a receiving hopper. From here the ashes are taken by means of a belt conveyor on to barges.

Boilers.—The boilers are arranged in two rows facing each other, with a single firing aisle, 20 feet wide, running between them. The building has to accommodate 72 boilers, of which 60 are installed. They are of the Babcock & Wilcox type and have a heating surface of 6,008 square feet each, made up of three 42-inch drums and 14 by 21 4-inch tubes. The boilers are designed for 200 pounds working pressure.

There are two different styles of grates, 42 are of the Roney stoker type and 18 hand-fired. However, at present additional mechanical stokers are being installed. The mechanical stokers have a grate surface of 111.8 square feet, while the hand-fired have 100 square feet. A forced draft system has been installed for the hand-fired grates.

Experiments are being carried on on some of the boilers at present by placing a second furnace in the rear of the present furnace, a system similar to the Hornsby horizontal boilers (10,850 square feet) installed in the Bow Street station, London.

Twelve boilers have been provided with superheaters (8 having a heating surface of 768 square feet each, and the remainder 900 square feet each), and supply steam to the turbines and one adjoining prime mover. It was this prime mover that was tested and reported before the American Institute of Electrical Engineers in January, 1906.

Removal of Gases. — As already pointed out, the plant is arranged on the unit system. For each chimney there are 12 boilers arranged in batteries of two, three batteries on each side of the firing aisle. For such a unit there are four economizers, as will be seen later. From the rear of each boiler two smoke uptakes rise and join by means of a sand-packed expansion joint to a horizontal flue located on the economizer floor. The economizers may be by-passed, if necessary, and the gases discharged directly to another large rectangular uptake, entering the chimney at the sides. The circular uptakes are lined with 4-inch hollow radial brick, while the horizontal flues, of which there are four for each chimney, are lined with 8-inch brick. Two of these latter are connected by one vertical riser to the chimney.

A notable feature is the way the radial brick chimneys are carried on the steel work of the building some 84 feet above the basement floor. The diameter at the top is

15 feet and is 218 feet above the grates. This subject is more thoroughly treated in the article on chimneys.

Feed-Water Supply.—As already pointed out, for each six boilers there is installed one boiler feed pump, located at the side of the generating room, together with the condenser pumps. These pumps are of the vertical compound duplex type, 12 inches by 17 inches by 15 inches, capable of handling 100,000 pounds of water per hour, against a head of 225 pounds. As the feed water is drawn from the city main, large storage tanks had to be installed, so that in case of emergency the entire plant would not have to be shut down. There are at present eight tanks installed in the basement of the boiler room beneath the firing aisle, each having a capacity of 2,200 gallons.

Eleven closed vertical feed-water heaters are arranged above the pumps in the pipe area, having a total heating surface of 5,500 square feet. It may be stated here that these heaters have already been removed and replaced by open feed-water heaters.

The boiler house was designed for the installation of economizers, but with the first equipment only four were installed, this number having recently been increased to 14, giving a total heating surface of 107,600 square feet. The plant is arranged for a total installation of 24 economizers.

Main Steam Piping. — One of the most noticeable extravagances in this power plant is the main steam piping. From each of the six 600-horse-power boilers a 9-inch pipe leads to an 18-inch (O.D.) header, which enters the pipe area where it joins a short vertical manifold. This pipe area is 18 feet wide and 15.5 feet above the floor of the main generator room, and separated from the latter by a partition wall. It runs the entire length of the generating room, and contains the so-called equalizing pipe system, besides the heaters. The purpose of this system is to assure against accidents and to equalize the pressure in all steam mains throughout the entire plant, so as to facilitate the paralleling of all units. There are ten vertical manifolds for the ten-unit plant, which are interconnected by a system of three 10-inch pipes.

As the power house is 693 feet long, it will be seen that the expansion of these equalizing pipes, which run the entire length of the power house, is enormous. The pipes between consecutive manifolds are therefore shaped in the form of a return "U," thus giving the entire equalizing pipe system a serpentine effect.

From the top of each manifold two 14-inch sweeping steam down-takes lead to the basement of two separators at the base of the engine foundations. The height of these down-takes is approximately 60 feet. From these separators, which are 3 feet in diameter and 10 feet long, two 14-inch pipes lead upward some 15 feet to the bottom of the engine cylinders. Each engine is therefore provided with two throttle valves, which forces the attendant in starting this unit to go from one valve to the other. Near the engine, as well as at the boiler outlet, quick-closing valves are provided. A great number of valves have been installed in the pipe area, a large percentage of which extends through the partition wall to a gallery overhanging the generating room, from where they may be operated.

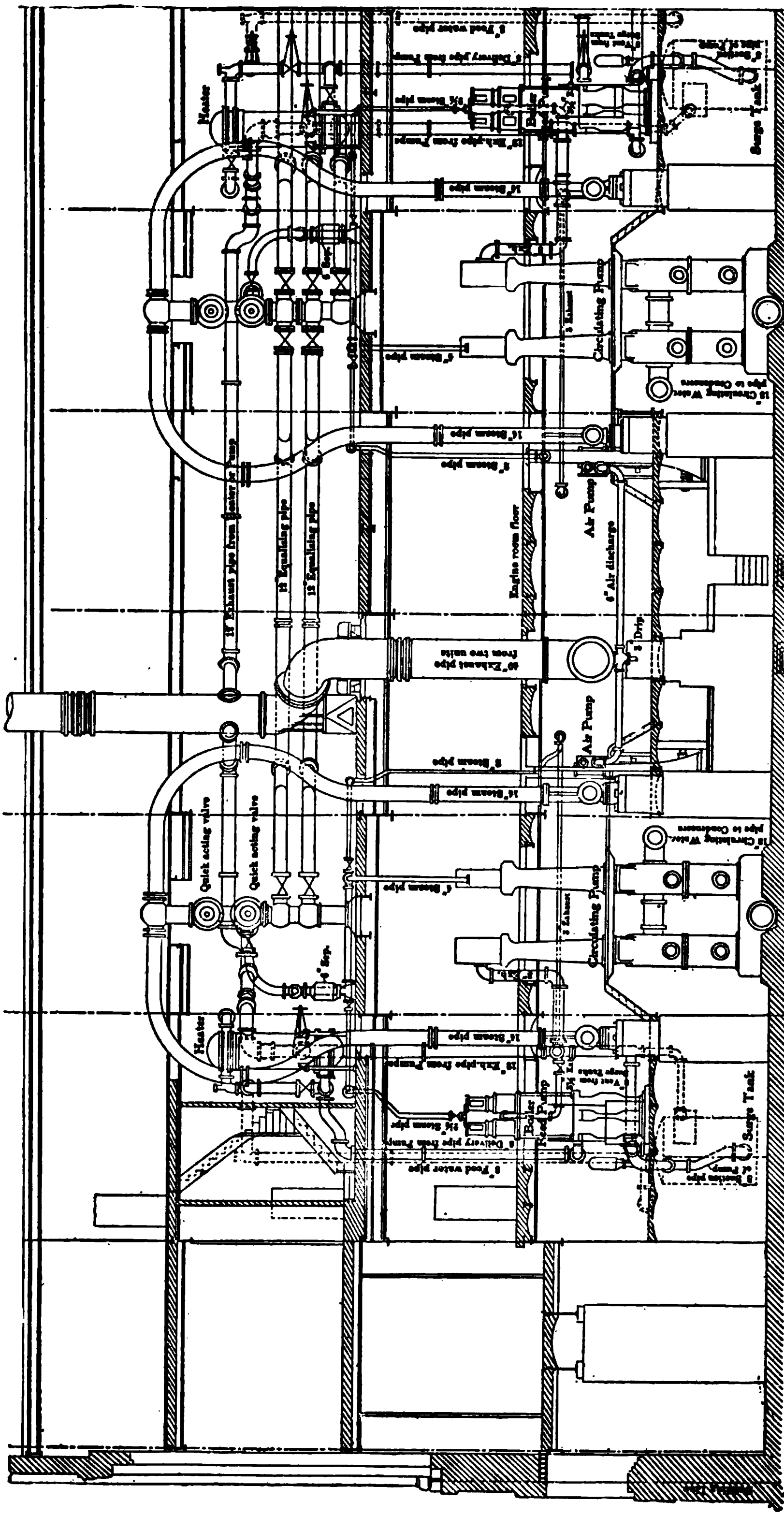


FIG. 5. Arrangement of Pumps and Piping, 59th St. Plant, New York (*American Electrician*).

Considering the pipes, one is immediately impressed with their enormous size. For instance, the 9-inch pipe at the boiler should have been 6 inches, while instead of two 14-inch pipes for each prime mover (5,000-K.W. unit), one would have been far better, not only on account of efficiency of operation but also first cost. Thus the velocity of steam would have been in the neighborhood of 6,000 feet per minute, which is common for American practice with the use of saturated steam.

Considering the 10-inch equalizing pipe system, the total length of which is 1,390 feet, it seems rather extravagant on account of the improbability of a break-down, espe-

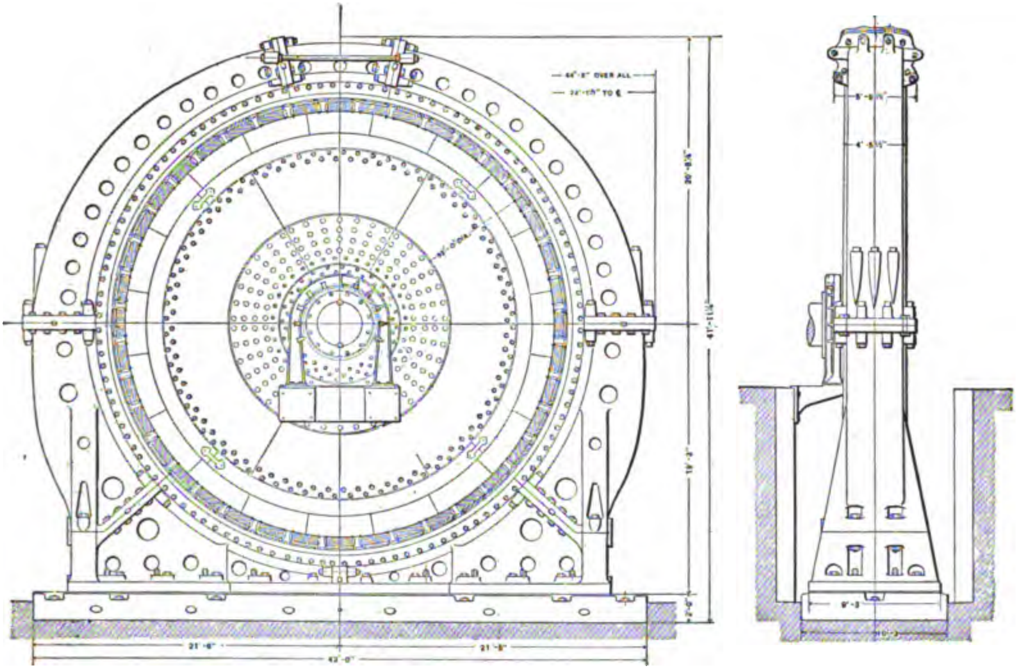


FIG. 6. 5,000-K.W. Alternator, 59th St. Plant, New York (*Street Railway Journal*).

cially as the designer pointed out that all piping was designed 50 per cent stronger than the so-called "extra heavy" piping.

The total length of the main steam piping for the present equipment (50,000 K.W.) is 6,430 feet. This does not include the auxiliary piping, which is of considerable length and size. All fittings are of special design, thus still further increasing the cost.

In order to make possible a comparison of power plant piping costs, it is of interest to note that the entire piping of the plant amounts to approximately $450,000, or $9.00 per K.W. normal capacity.

Main Prime Movers. — The plant has been laid out to accommodate twelve 7,500 horse-power Allis-Chalmers combined horizontal vertical cross compound engines (see article on reciprocating engines). There are, however, only nine installed at present, while space is left for two additional units, which will in all probability be turbines.

After the plant had been laid out it was decided to install instead of a tenth engine unit four 1,250-K.W. Parsons turbines (three at present installed), as may be seen in the accompanying plan. These turbines occupy the space between engines Nos. 6 and 8. Upon the shafts of the main prime movers are mounted 5,000-K.W., 25-cycle, 3-phase, 1,000-volt, revolving field alternators, having a speed of 75 R.P.M.

Main Condenser Plant. — Each prime mover is provided, as they are of the combined system, with two Alberger barometric tube condensers. The condensing cham-

FIG. 7. Low Pressure Side of Engines and Condensers, 59th St. Plant, New York.

bers are connected by an equalizing pipe, so as to carry a uniform vacuum in each. Each set of condensers has its own circulating pump and air pump. These pumps, together with the boiler feed pumps, are located on one side of the generator room, beneath the pipe area. The pumps are of the vertical type, as it was the intention to keep the steam cylinders of all the pumps here located above the main floor, so that the engine attendant might easily watch the operation of the same. However, with the change of location of the condensers from the pipe area to the opposite side of the

engine room, difficulties were encountered with the air pump, the result of which is that the entire air pump is below the main operating-room floor.

The circulating pump, is of the vertical double-acting compound type, 14 × 20 × 30 × 20 inches. The suction of the pump is 24 inches while the discharge to the condenser is 18 inches, which branches into two 14 inches to each condenser vessel. All the pumps are cross connected so that one may be used on an adjoining condenser. The air pumps are single acting, the steam cylinder being 8 inches diameter, 24 inches stroke and run at a speed of 80 R.P.M. The tail pipe discharges into a reinforced concrete hot well. Should the engine run non-condensing an automatic relief valve discharges the steam to the atmosphere through two 30-inch riveted steel plate pipes, connecting to a 40-inch riser, which takes care of two engines, increasing, after passing through the roof, to 48 inches, on the top of which is an 8-foot exhaust head. In the horizontal lines and in the lower end of the vertical riser, corrugated copper expansion joints are installed; in the upper end of the vertical riser there are two slip expansion joints.

Turbo-Generators. — For lighting the subway three Westinghouse-Parsons turbo-generators are installed. These are of 1,250-K.W. capacity, 3-phase, 60-cycle, 1,100-

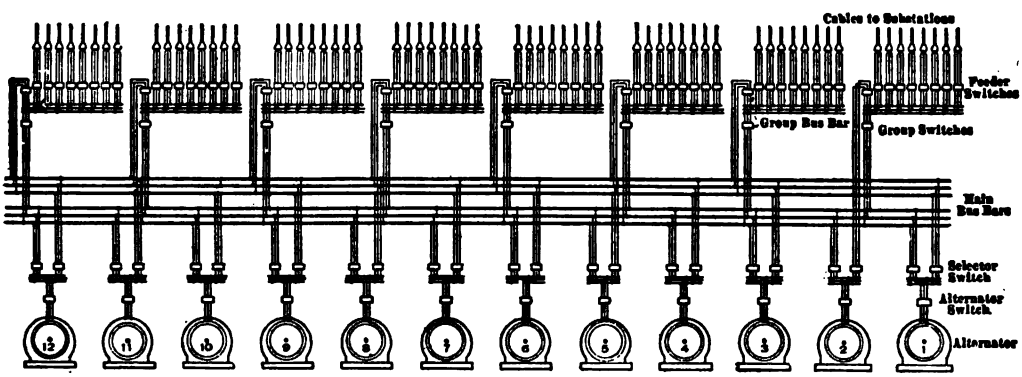


FIG. 8. General Diagram of 11,000-Volt Circuit, 59th St. Plant, New York.

volt. Space is left for a fourth similar unit. Each turbine has its own condenser equipment, consisting of a surface condenser, 4,500 feet cooling surface, a horizontal two-stage dry vacuum pump, and a horizontal duplex hot well pump. The three condensers are supplied with circulating water by one 16-inch centrifugal pump, direct-connected to a 9 × 15 × 9 inch compound engine. The entire condenser equipment is located directly beneath the turbines.

Electrical Equipment. — There are two Westinghouse vertical cross compound (17 × 27 × 24 inches) engines, direct connected to 250-K.W. 250-volt generators, running at 150 R.P.M. There are also three 250-K.W. motor generator sets. The steam-driven exciters are located, as will be seen in the plan, at the end of the turbines (prac-

tically in the middle of the plant), while the motor generators are not, as shown in the plan, between the steam driven exciters, but distributed between the main generator units, although kept near the middle of the plant.

A 120-cell storage battery is installed to float on the exciter buses, having a one-hour capacity of 3,000 amperes.

Switching Room. — The room set apart for switching purpose is 23 feet wide and runs the entire length of the generating room, and consists of three floors. However, the switching apparatus does not occupy the entire space of the third floor, as there are rooms left for offices, repair shops, etc. The generator leads run beneath the main engine-room floor, in clay ducts, to the gallery in the basement, where the two sets of main bus-bars are located, the latter running practically the entire length

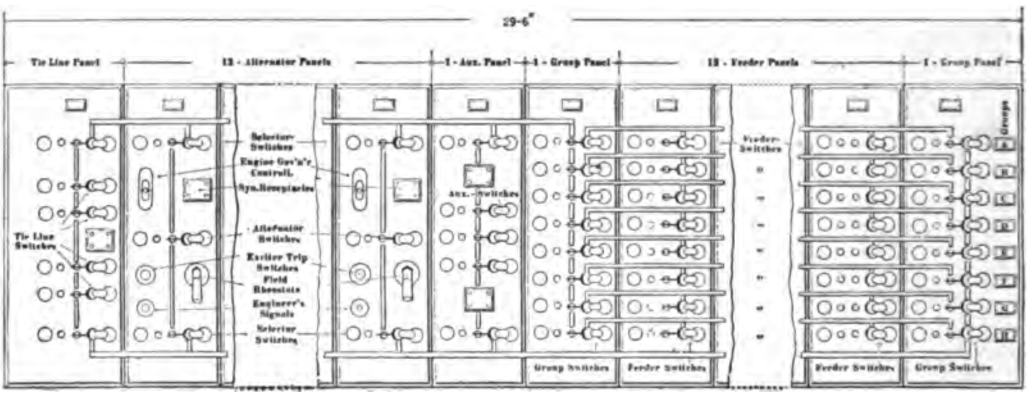


FIG. 9. Diagram of the Main Controlling Board, 59th St. Plant, New York.

of the building. The generator switches and the feeder switches, which are all of the motor operated oil type, are arranged on the engine-room floor level. Some 29 feet above the engine-room floor is the controlling-room gallery, containing the various switchboards; the controlling benches are located practically opposite the center of the engine room. There is no high-tension current whatever in this gallery, as the 11,000-volt oil switches are operated by motors supplied from a storage battery of 55 cells. Complete dummy bus-bar system is laid out on top of the bench, in order to simplify the operation, especially for new attendants. The complete switchboard equipment is as follows: One board for generator and feeder instruments, one operating bench for generator and feeder oil switches, one exciter current switchboard, one for auxiliary power, one operating bench for 60-cycle (subway lighting system), one board for 60-cycle system instruments and one board for power plant lighting.

The wiring diagram is shown in Chapter VIII, where also some other illustrations of the electrical equipment are given. The accompanying cut shows the bus-bar system of this plant and is self-explanatory. The oil switches used are of the General Electric Company's motor operated type. Each generator has one main and two selector oil switches. There is one group bus for each eight feeders and two selector switches for each group bus.

Cranes. — The generator-room cranes are located 68 feet 7 inches above the main operating floor. There are installed two cranes, one having a capacity of 50 tons and the other of 25 tons. The former has two hoists, one 50-ton and one 10-ton, so that the smaller material may be more rapidly handled. The span of these cranes is 72 feet.

Oiling System. — The plant is equipped with a gravity ring oiling system, consisting of duplicate 4-inch mains. The oil from the various prime movers returns by gravity to filters located at one end of the power house, where it is purified and pumped to two elevated tanks by means of two steam actuated piston pumps. The supply tanks are located at a height sufficient to create a head of 25 pounds. The return piping is of wrought iron, the supply piping of brass.

There are two filtering tanks having a capacity of 13,000 gallons, and containing 1,200 canvas bags, 3 inches in diameter and 10 inches long. These bags are so arranged that they may be readily removed and replaced by clean ones.

CHELSEA PLANT, LONDON.

The above-named station furnishes the power for the London underground railway and is the most prominent station in Great Britain. The total normal capacity amounts to about 42,700 K.W.

The plant is located on Chelsea Creek at its junction with the Thames River. Fig. 1 shows the location of the plant and its various auxiliary requirements. The most prominent feature, besides the main building, is the large basin to facilitate the handling of coal, and a separate building containing an oil-cooling plant.

Substructure. — Great difficulty was encountered in the foundations, as same had to be carried down some thirty-five feet, and a retaining wall had to be built along the entire water front of the site. Some 98,000 cubic yards of earth were excavated over the entire lot, and 40,000 cubic yards of concrete were used in the substructure. These figures include the excavation and concrete floor for the barge basin, which is 220 feet long by 80 feet wide.

Circulating Water Supply. — In order to supply the circulating water, a pipe system has been installed from the Thames to the power house, as may be seen in Fig. 1. The valve chamber is located close to the Thames on the side of the barge basin. From the middle of the Thames to this valve chamber two 5-foot 6-inch cast-iron pipes have been embedded in the river bottom. From this point on the pipes are of wrought iron, running under the barge basin and oil-cooling house into the engine room. The pipes reduce at each suction connection in the engine room and are at the final unit 2 feet 6 inches in diameter. One of the pipes is used as an outlet and the other as an intake; they are cross connected, so that their duties may be reversed, that is, the outlet may be used as the intake, and *vice versa.* By this means the pipes become self-cleaning,

as any accumulation of dirt in the intake will be washed out when the pipe is used as an outlet.

Coal Handling System.—The barge basin is constructed of granite blocks of about five tons each, while the floor is of 12-inch concrete reinforced with expanded metal, and is large enough to accommodate six barges at one time. A pneumatically operated gate is provided at the entrance to the basin, so as to keep the water level constant with the high-water mark of the river. A by-pass gate 48 inches in diameter is also provided to regulate the water level in the basin.

Two electrically operated gantry cranes unload the coal by means of 1½-ton grab shells upon a 15-horse-power motor driven 30-inch belt conveyor, which carries the coal to a point near the building, emptying into two bucket conveyors, which elevate

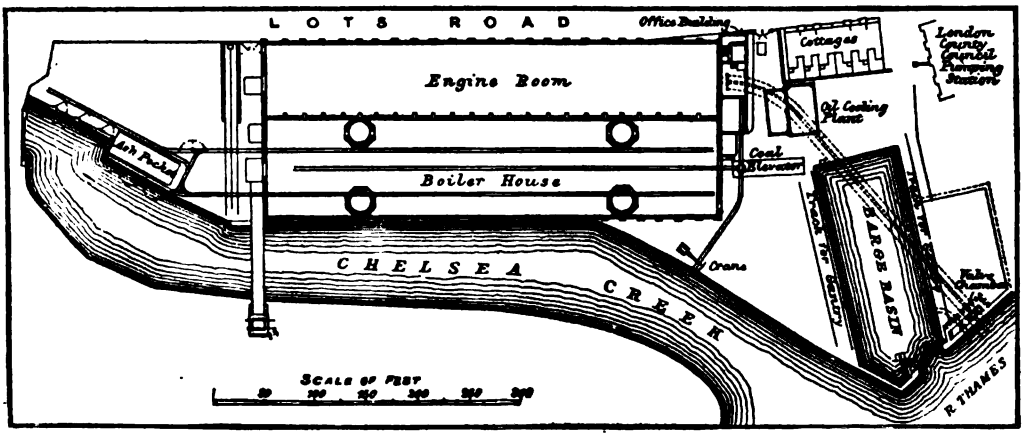


FIG. 1. General Plan, Chelsea Plant, London (*The Tramway and Railway World*).

the coal above the coal bunkers in the boiler room (some 145 feet high), from which it is distributed by means of two 24-inch belt conveyors to the various bunkers. Each bucket conveyor is operated by a 30-horse-power motor, while the 24-inch belts are driven by 20-horse-power motors. Arrangement has been made for taking the coal from the western end of the building, from the siding of the West London Extension Railway. This railroad is on the opposite side of the Chelsea Creek and it will be necessary to install a bucket conveyor, overspanning the creek and running to the top of the boiler room, where the coal may be dumped on the two horizontal belt conveyors above mentioned.

Superstructure. — The power house is 453 feet long, 175 feet wide and 140 feet from the basement floor to the peak of the boiler-house roof. It is divided by a partition wall, which separates the boiler and engine room, the former being 100 feet wide and the latter 75 feet wide. This also includes the space required for the switching department.

The boiler room is designed with a basement 19 feet high, and has two tiers of boilers; the lower tier is 33 feet high. Above the second tier is a coal bunker, capable of holding 15,000 tons. Accommodation is made for 80 boilers, each having a heating surface of 5,212 square feet. At the present, however, there are but 64 of these boilers installed.

The generating room, which has a basement of the same height as that under the boiler room, is 50 feet high between operating-room floor and bottom of the roof truss. The total height from basement to the peak of the roof is 100 feet. A space of 14 feet width is set apart for the entire length of the generating room for the switching room. The ten 5,500-K.W. turbine units are arranged in two rows and staggered; the condensers are placed in the basement between the two rows. By studying the cross-sections of the plant one will notice that, with the exception of the generating room, the design has been followed of the 74th Street station in New York, for instance, the arrangement of the boilers in two tiers, with the economizers in the rear of the boilers, the coal bunkers,

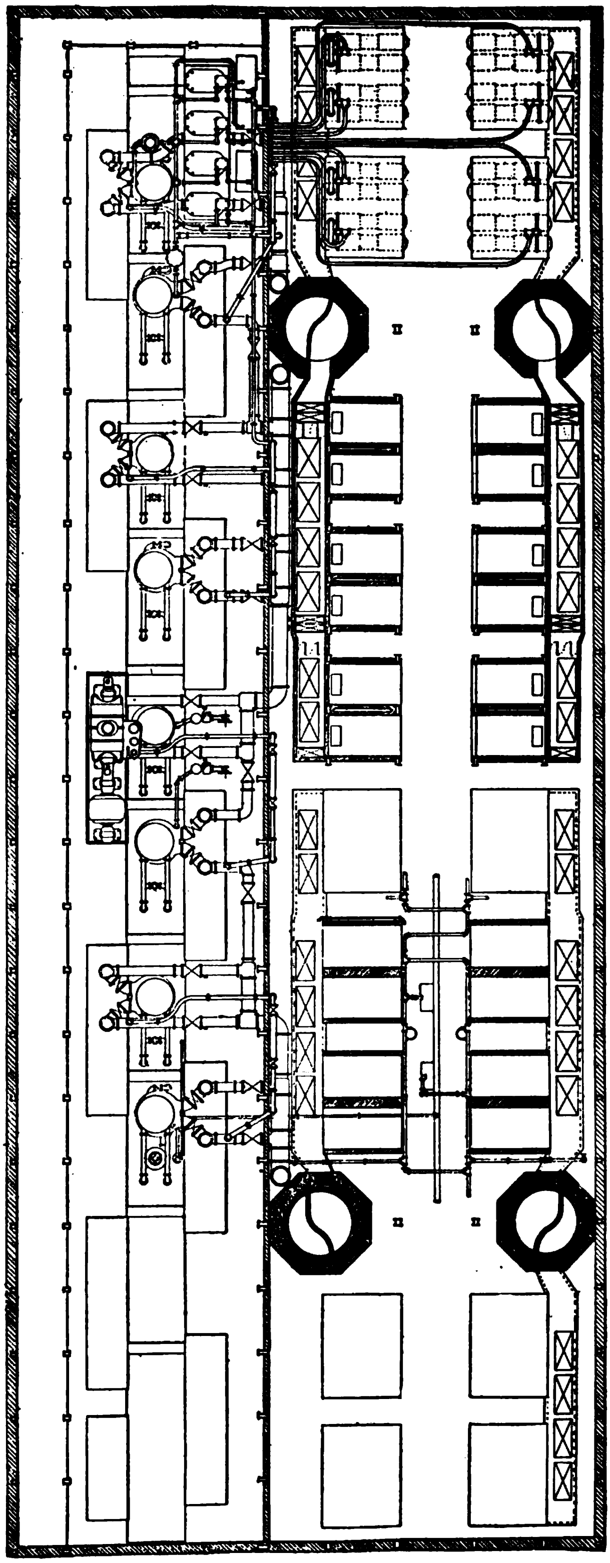


Fig. 2. Plan of Chelsea Plant, London.

the arrangement of the chimneys, etc. Besides this the main steam-pipe system is laid out on the same principle as that at the 74th Street plant, which is, although

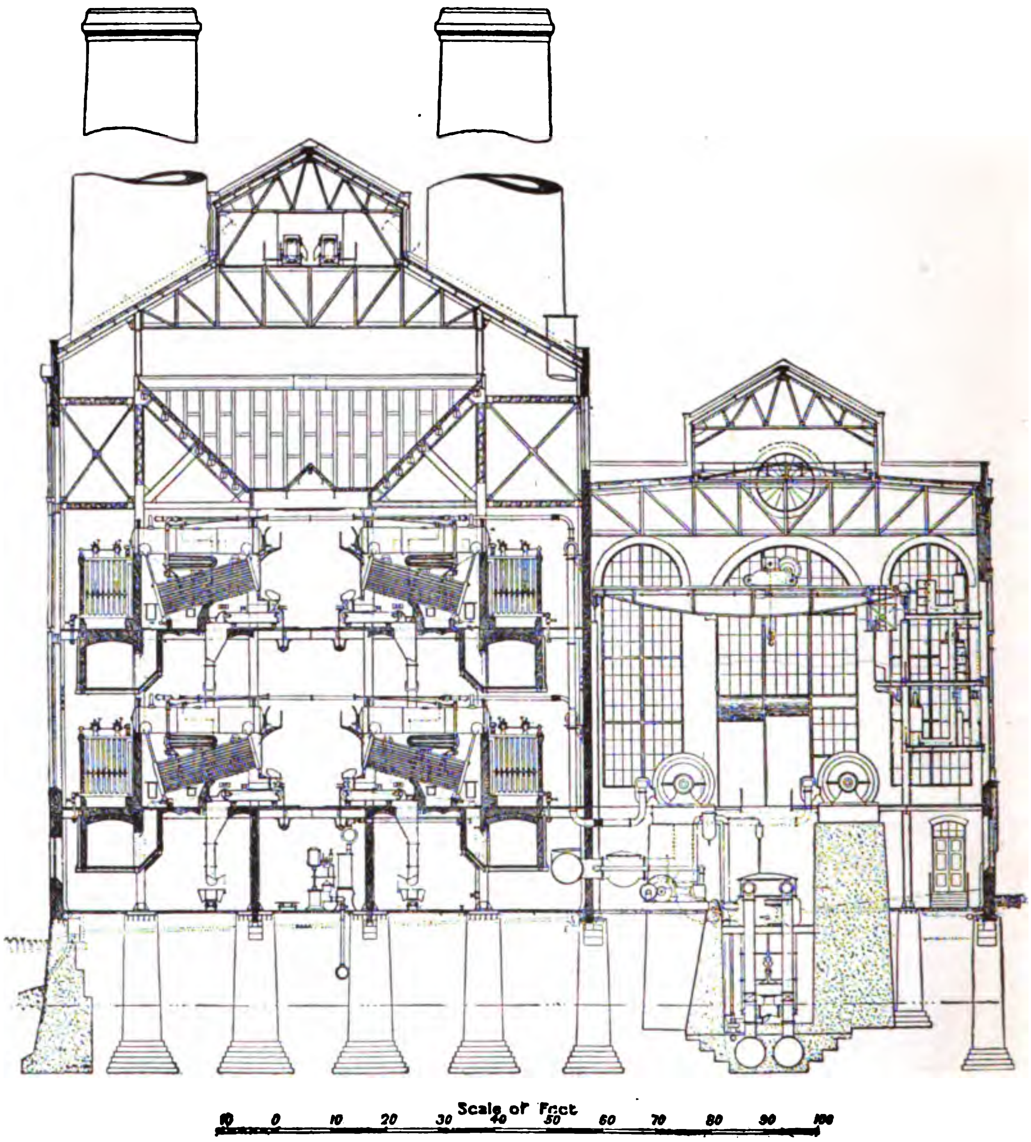


FIG. 3. Cross-Section of Chelsea Plant, London.

flexible, a very expensive system and could easily be simplified. There are, however, some exceptions, as, for instance, chain-grate stokers, instead of incline stokers, and the installation of a superheater.

The steel work for the superstructure and the walls are self-supporting. The

following table, as given in *The Tramway and Railway World*, gives the material used in the building:

Fletton bricks (9" × 4½" × 3")	6,000,000
Terra Cotta in strong courses, arches, cornices, etc.	17,000 cu. ft.
Specially made arch brick, all of different pattern	85,000
Red pressed facing bricks	85,000
Portland cement	600 tons.
Hydraulic lime	260 "
Glass in windows	50,000 sq. ft.
Paint	25 tons.
Steel work in framing and structure	6,000 "
Sundry steel and ironwork not included in main structure	2,000 "

Boilers.—The boilers are of the Babcock & Wilcox type and are arranged in two rows in each tier, two boilers in a battery, each having a heating surface of 5,212 square feet. They are capable of evaporating 17,000 to 18,000 pounds of water per hour. The tubes employed are arranged in twenty sections, twelve high. The boilers are designed for 175 pounds working pressure.

The mechanical stokers are of the motor driven chain-grate type, two stokers for each boiler, and have a total area of 83 square feet. The coal is fed to the stokers through chutes from the coal bunkers, while the ashes drop into a suspended steel hopper and are carried away by means of a storage-battery locomotive on a narrow-gauge railway to an ash pocket outside of the building, or may dump into barge, if same is at hand.

In the front of the boilers, directly beneath the drums, galleries are provided interconnected to all other boilers in the same row to facilitate operation and repairs.

A superheater of 672 square feet heating surface is installed in each boiler, capable of producing a temperature of 150° Fahr., which would mean a total temperature of 530° Fahr. These superheaters are of the Rosenthal type, as manufactured by the Babcock & Wilcox Company. The usual arrangement is made to flood these superheaters.

Economizers.—As practically in all European power plants, this station has been provided with economizers. Each economizer is made up of two groups of tubes. There are eight economizers of 288 tubes each, and twelve consisting of 576 tubes each. The total heating surface of this economizer plant, which is of the Green type, amounts to 105,000 square feet. By the extension of the plant, eight additional 288-tube economizers will be installed. It will be noticed that this economizer capacity is an extremely large one.

Feed Water. — The basement of the boiler room is divided into three sections. The two outer sections beneath the boilers are for removing ashes, while the center one beneath the fire aisle is for boiler-feed pumps, etc. There are installed eight vertical simplex compound pumps with center packed plungers, each having a capacity of 18,000 gallons (British) per hour.

Feed water is taken from a storage tank located in the oil-cooling house (see Fig. 1). The water is supplied to this tank from an 8½-inch artesian well, 575 feet deep. Should this well fail or should the water line in the tank become low, an auxiliary connection is made from the city main, provided with a float valve. Besides, this further pre-

FIG. 4. Interior of Generating Room, Chelsea Plant, London.

caution is taken by installing two pumps, which have their suctions connected directly to the river. As all of these feed-water pumps are steam driven, the exhausts are brought to a feed-water heater.

Chimneys.—There are four radial brick chimneys, having a diameter of 19 feet and being 253 feet above the grates of the lower tier of boilers. The foundations are 42 feet square and have a depth of 34 feet 6 inches; the concrete for each foundation amounts to 2,000 cubic yards. The smoke may pass either directly through the economizers to the chimney, or may be by-passed, in which case it passes through a flue suspended from the floors.

Turbo-Generators. — The turbo-generators are of the British Westinghouse type and are double flow. There are at present installed eight 5,500-K.W. units, with provision for two similar units, and one of 2,700-K.W. capacity. The turbines are direct

connected to 3-phase, 11,000-volt, $33\frac{1}{3}$-cycle revolving field generators, operating at 1,000 revolutions per minute.

The turbines are designed to work at a pressure of 165 pounds and 100° Fahr. superheat, and permit of an overload of 50 per cent, with a vacuum of 26 inches and 27 inches.

The guaranteed steam consumptions of these turbines, per electrical horse-power hour, are as follows:

Load.		26" Vacuum.	27" Vacuum.
One and one-quarter load	6,875 K.W.	16.0	13.6
Full load	5,500 "	15.6	13.2
Three-quarter load	4,125 "	17.2	15.0
One-half load	2,750 "	18.4	16.0

The guaranteed electrical efficiency of the generators on non-inductive load is as follows:

Full load	97.50 per cent.
Three-quarter load	96.50 "
One-half load	95.00 "
One-quarter load	90.00 "

The entire turbo-generator unit is 48 feet long, 11 feet 4 inches wide at floor level and 13 feet 9 inches high (above floor); the turbines have an overhanging platform which gives a total width of 17 feet.

Piping. — Steam is drawn from the boilers through 6-inch solid drawn mild steel pipes, eight of which join in one 14-inch pipe header, which is of lap-welded steel from which the connections are run to the turbines. Besides these connections there is a separate auxiliary header of 10-inch pipe connected at three points with the main steam header. The 6-inch pipes are provided with screw flanges; the 10-inch and 14-inch are provided with flanges riveted to the pipe. All flanges are of forged steel.

Due to the double flow type turbine, each unit is provided with two exhaust outlets of 44 inches diameter, while the atmospheric exhaust line provided with a relief valve is connected to a riser 5 feet in diameter, made of riveted mild steel, with cast-iron tees and bends. It is the author's opinion that instead of employing a 60-inch exhaust riser, a 30-inch pipe would have done as well, for the liability of a break-down of several condensers, discharging into a single exhaust riser, is doubtful, and in modern practice condenser plants should be installed, so that one may figure on a higher degree of reliability. Taking into consideration that there are three risers, each 106 feet long, and that the cast-iron bends employed weigh not less than 7 tons each, it will readily be seen what expense this involves.

Condenser Plant. — The condensers are of the vertical cylindrical surface type, having a cooling surface of 15,000 square feet and made of 1-inch tubes. Each tur-

bine has its own condenser, which is provided with a 20-inch centrifugal pump, operated by a three-phase motor, and as the top of the condenser is some 29 feet above minimum low water after the circulation has been established, a siphoning action takes place. Each condenser is further provided with an electrically driven dry vacuum pump, and a 4-inch electrically driven centrifugal hot well pump. The water of condensation is returned by means of the latter named pump to the feed-water tank, from which the boiler feed pumps return it to the boiler. The vacuum maintained in the condensers is about 27 inches. The only additional feed water necessary is that which is consumed by the steam driven auxiliary machinery, leakage, etc. Considering this, and also the high temperature that must be maintained in the smoke flue, due to the superheaters, it would seem that the economizers were needlessly large, as the heating surface of the total boiler capacity is 332,568 square feet and that of the economizers is 105,000 square feet, or approximately 3 square feet of boiler surface to one square foot of economizers.

Exciters. — There are four steam driven exciters installed at the east end of the generating room, having a total capacity of 600 K.W., amounting to practically 1 per cent of the present plant capacity. The engines are of the two-cylinder compound enclosed type, running at 375 revolutions per minute, and are direct connected to the generators mounted on the same bedplate. They are capable of withstanding a 25 per cent overload.

Oil-Cooling System. — A separate building has been erected for cooling and filtering the oil. It has been stated that each turbine requires thirty-three gallons of oil per minute to circulate through the four bearings of each turbo-generator set, amounting to 264 gallons per minute for the eight units. This building is some 50 feet high and contains in the basement and ground floor three oil tanks, while the third floor accommodates oil filtering and gravity tanks, with a total capacity of 20,000 gallons. The second floor, as previously mentioned, is occupied by the feed-water storage tanks.

Four oil mains of 6 inches diameter, a supply and a return having a head of 30 feet, run the entire length of the basement. The oil, after passing through the various bearings, returns by gravity to the oil-cooling building, whence electrically driven centrifugal pumps force it through the cooling system and up to the filtering and gravity tanks located on the top floor. This practice is entirely contrary to that usually employed, as it is natural that when the oil is hot it is thinner and precipitation of foreign substance is much more easily accomplished than with cool thick oil; in fact, oiling systems are installed in which the filtering tanks are provided with steam heating systems to facilitate the above-mentioned precipitation.

The cooling system installed in the Chelsea plant is the reverse of a surface condenser. The oil is forced through a number of brass tubes, while the cooling water drawn from the Thames surrounds these tubes. There are three of these installed, each having 330 square feet of cooling surface. The total working capacity of this plant is 350 gallons per minute.

Switching Room.—As previously stated, a space of 14 feet is set apart for the switching compartment, which contains four floors. The floor in the switching room on the level with the generating-room floor is practically empty, while the second floor, 11 feet 6 inches above this, is occupied by the main generator oil switches, in the rear of which are the static discharges, while at the end is the auxiliary switchboard. The third floor, 11 feet 6 inches higher, is the main operating floor. A platform some 8 feet wide, supported by brackets from the crane and switching-room columns, overhangs the generating room. This platform contains the generator instrument board and the controlling bench, and makes the entire generator room visible to the operator. Directly at the back of the gallery, in the switching room itself, are the feeder panels, in the rear of which are the main junction switches, the high-tension generator bus-bars passing behind the latter, and at one end are the motor operated main rheostats; from here the leads pass to the fourth floor, which con-

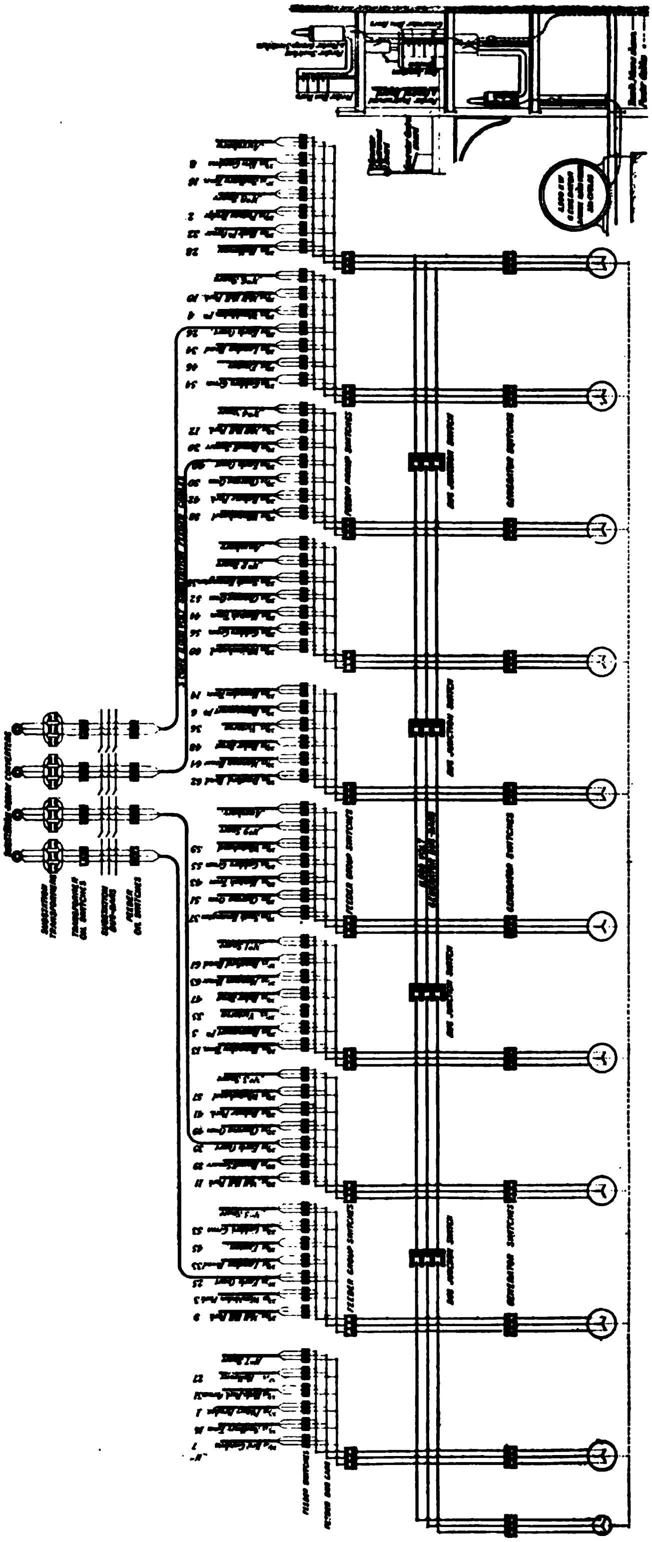


FIG. 5. Wiring Diagram of Chelsea (London) Power Plant and one Sub-station (*The Tramway and Railway World*).

tains the feeder bus-bars and oil-feeder switches with a passage between, under which the high-tension feeders have to pass. One end of this gallery is occupied by transformers.

The whole switching room is laid out with ample space, but the arrangement would certainly be improved if the high-tension feeders did not have to pass the low-tension main control apparatus. This could have been accomplished by placing the main bus-bars on the main generating-room floor level, and the feeder bus-bars and switches directly above on the second floor, leaving the controlling boards as at present located. This would not only have obviated the above-mentioned difficulty, but would have made unnecessary the fourth floor. As the feeders leave the building in the tile ducts beneath the basement floor, this would have materially simplified the switchboard arrangement, and would have avoided the carrying of the feeders some 40 feet above the generating-room floor and back again.

Auxiliary Electrical Equipment. — As the entire auxiliary apparatus, with the exception of the boiler feed pumps and exciters, is motor driven, this electrical equipment is of particular interest. The auxiliary switchboard consists of some twenty-four panels, for the control and distribution of current from four 125-K.W. exciters, nine single-phase 11,000—220-volt transformers, arranged in sets of three (aggregating 1,500 K.W.), one 125-K.W. synchronous motor generator, and two small storage batteries. From this board current is supplied for 89 three-phase, 220-volt motors, and twelve 125-volt continuous current motors. The total capacity of these units is nearly 2,000 horse-power. The above-mentioned motor generator consists of a 125-K.W., 220-volt, three-phase synchronous motor, and a 125-volt compound wound continuous current generator, used for charging the storage batteries and supplying continuous current for miscellaneous purposes. These storage batteries supply power for operating the oil switch motors.

Wiring System. — As will be seen in the cut, the wiring system is a very simple one, and has been laid out for ten main generator units; the two main generator units at the left hand and the small generator unit are for future installations. Contrary to the practice in most modern plants, a single bus-bar system has been installed instead of a double bus-bar or ring system, bus junction or sectionalizing switches being installed between every other two generators, thus giving the desired flexibility.

The feeders to any particular sub-station are so arranged that with the main bus junction switches open, current is drawn from different generators. This is a very desirable feature, as in case of break-down to any one of the feeder group buses the sub-station supply is not materially affected.

FISK STREET PLANT, CHICAGO.

In the Fisk Street plant an entirely new arrangement is adopted, it is claimed. This is the placing of the boiler room at right angles to the generating room. This claim is not quite just, since as early as 1898, Dr. Kennedy adopted this plan for the Edinburgh McDonald road, as has already been pointed out in Chapter II, on the general layout of power plants, and it is old English factory practice. The Fisk

Street plant, however, being the first prominent steam turbine (Curtis) plant, has been frequently copied in recent practice. This has been done, not for any saving in space, but for the simpler arrangement of piping and greater reliability of operation in case of failure of any of the piping. Besides this, better light and ventilation are secured.

The Fisk Street plant has been laid out for some 14 turbines, having a total normal capacity of 100,000 K.W., while the boiler room is laid out for 112 boilers. The original equipment of this station consisted of four 5,000-K.W. Curtis turbine units, and thirty-two 500-horse-power Babcock & Wilcox boilers. There have been added four 9,000-K.W. turbines and a correspondingly increased boiler capacity, but it may be some years before the 100,000-K.W. plant is completed.

As will be seen from the accompanying plan, the plant is located very favorably, directly on the north side of the South Branch of the Chicago River, the generating room proper forming practically the foot of Fisk Street. The plant is connected with both the C. B. & Q. and the C. & A. railways by sidings, which give ample facilities for coal and ash handling as well as building material and machinery. On both sides of the plant are two canals, running parallel with the plant, Mason's and Allen's. The condenser water is drawn from the former and is discharged into the latter. It will be seen that this is almost an ideal site for a large power plant. Large coal storage facilities are provided.

A separate two-story building, 460 feet long, has been provided for switching purposes, and runs alongside the generating room.

Building. — The entire building and all machinery rest upon piles, driven down to hard pan and capped with concrete foundations. The superstructure embodies a self-supporting steel skeleton; the walls are of hard-pressed red brick, giving a plain and substantial, but very pleasing effect. The walls of the generating room are faced with white enameled brick, while the floor is laid with hexagonal tile. This station, as well as the Boston "L" Street station, shows marked progress in the architectural features of power plants.

The generating room is 65 feet wide and 65 feet to the top of the roof truss, the crane runway is 50 feet above the floor, and the total length of the plant when completed will be some 820 feet. The turbines are spaced 41 feet, center to center. There are one 50-ton crane and one 60-ton crane installed.

On both sides and running the entire length of the generating room are galleries, one towards the boiler room to facilitate operation, and the other a so-called visitors' gallery.

The boilers are arranged back and back, leaving 5 feet space between the setting at the rear as well as at the side, while the firing aisle is 29 feet wide, *i.e.*, from face to face of boiler setting. The basement is 16 feet high, while the bottom of the coal bunker is 31 feet 6 inches above the operating floor, the bunker, being 18 feet 6 inches deep, is practically directly below the roof truss. The total height of the building from the basement to the top of the louver is 75 feet. Above each firing aisle is run a hand crane of 5 tons capacity.

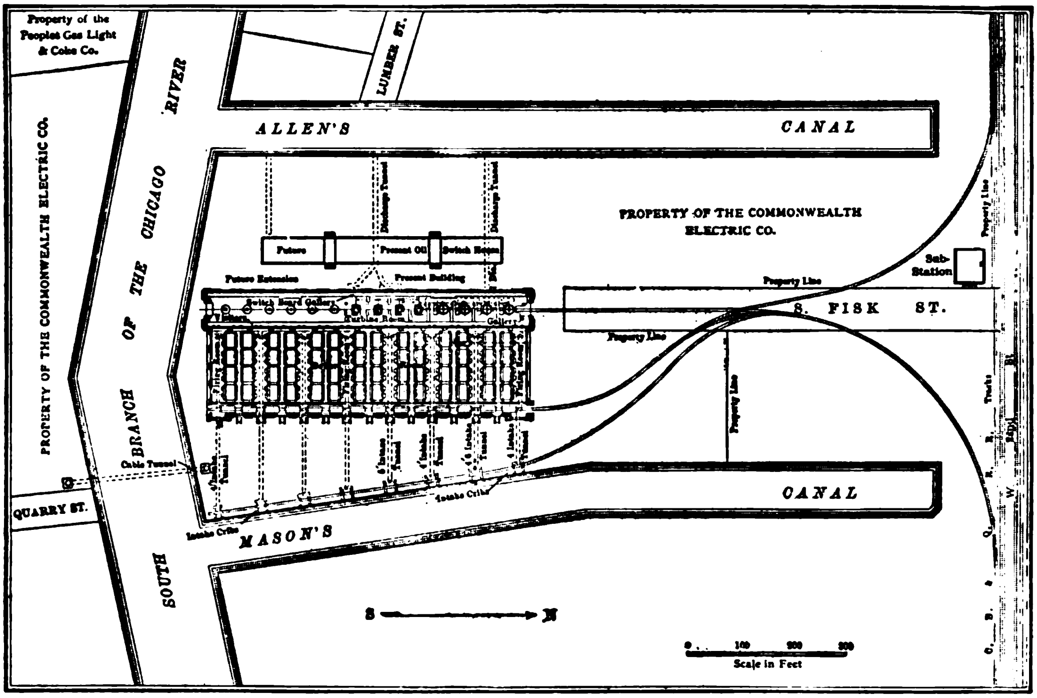


FIG. 1. Location of Fisk St. Plant, Chicago (*Power*).

FIG. 2. North End of Fisk St. Plant, Chicago.

The chimneys, of the lined steel type, are carried on the boiler and building columns and have an interior diameter of 18 feet, and a height of 205 feet above the grates for the 5,000-K.W. units, and some 50 feet higher for the 9,000-K.W. units. One chimney serves for 8 batteries or 16 boilers.

Boiler-Room Equipment. — The boilers are of the Babcock & Wilcox make and have a heating surface of practically 5,000 square feet and consist of 2 drums and 252 tubes, arranged in 18 headers of 14 tubes each. The superheater has approxi-

FIG. 3. Firing Aisle, Fisk St. Plant, Chicago.

mately 900 square feet, and is guaranteed to produce 150° Fahr. superheat under normal working conditions and gauge pressure of 180 pounds. The boilers are provided with chain-grate stokers, each having a grate surface of 85 square feet, and are belt driven from a shaft operated by one of the engines, one engine operating the grates for one row of 8 boilers, the other engine being kept in reserve. The ashes are dumped directly into a large lined ash hopper, suspended from the structural steel of the boiler setting, a smaller type of hopper being installed immediately in front of the main hopper to collect the fine coal falling through the grates. The ashes are carried away by the coal bucket conveyor into a concrete ash hopper at the end of the firing aisle, while the fine coal is brought back to the coal bunkers.

Steam Piping.—From the boiler a 6-inch steam pipe leads at the rear of the boiler in the basement to the so-called header room, where the main and auxiliary steam piping is located. The main header varies in size from 6 inches for a single boiler to 14 inches for a row of boilers of 8, the latter being the size of the main to the turbine. The steam headers are so interconnected that steam may be drawn from adjoining boiler rows. In this header room there are also placed boiler blow-off piping and two boiler feed-water mains, one so-called hot feed line, and the cold or auxiliary feed line, the latter having by-pass connections so arranged that one boiler feed pump, which is

FIG 4 Smoke Flues and Steam Down-Takes, Fisk St. Plant, Chicago.

placed at the side of the turbines in the generating room, may be used for cleaning the boilers. All these pipes are of wrought iron, with ground joint welded steel flanges.

Turbo-Generators.—The turbines are of the General Electric Curtis type, and were the first 5,000-K.W. units of this type ever built. Owing to this fact, the first three turbines are of the 2-stage type, while the fourth unit is of the 5-stage type. They are arranged in one row, each having a separate condenser. Four additional units of 9,000-K.W. capacity, each, are designed with a so-called base condenser, *i.e.*, the condenser frame is the base of the turbine. These latter units were designed for only 8,000 K.W., but during tests it was proved that they developed a maximum output of 14,000 K.W.

Cable Tunnel to Switch House

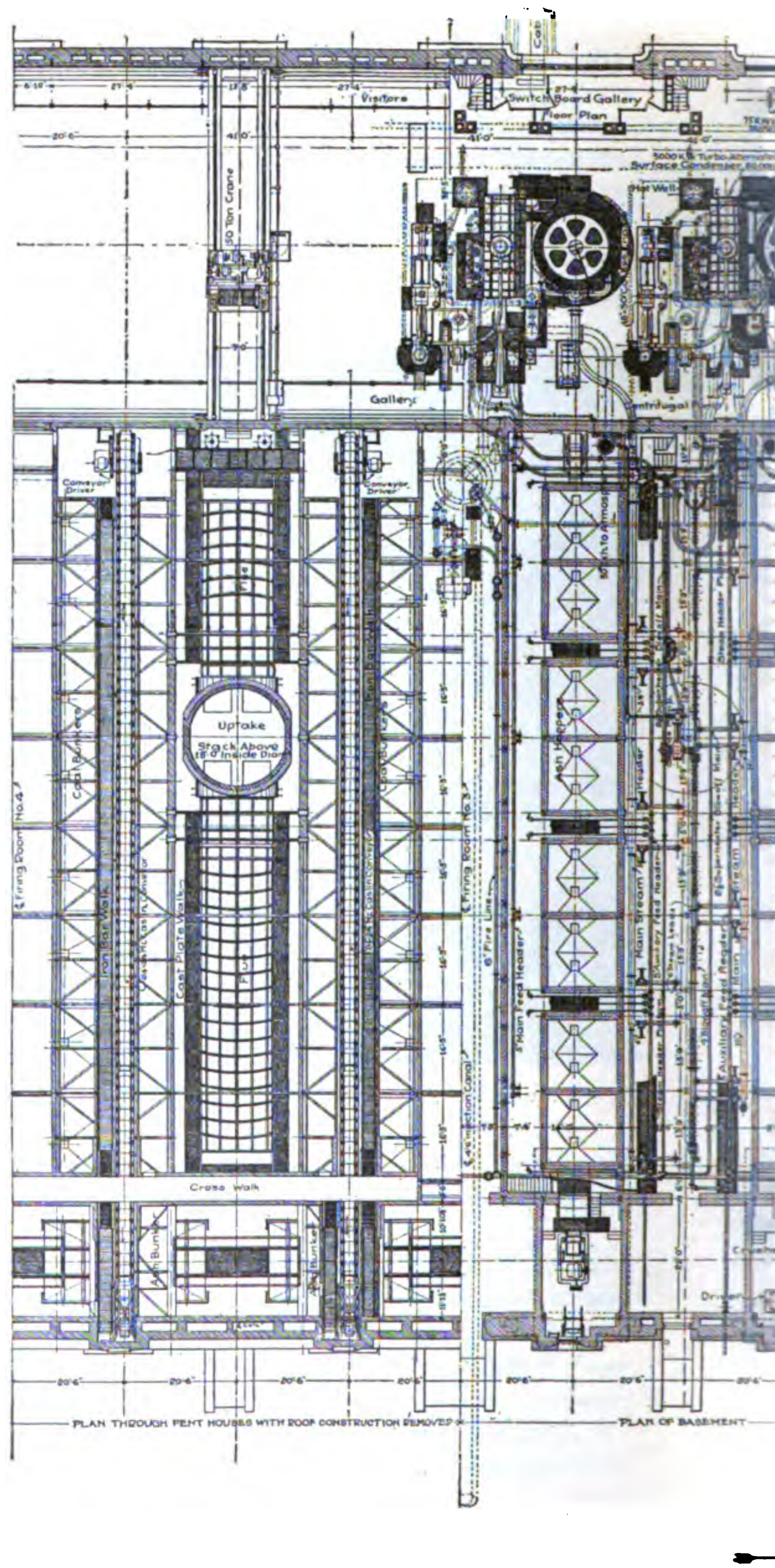
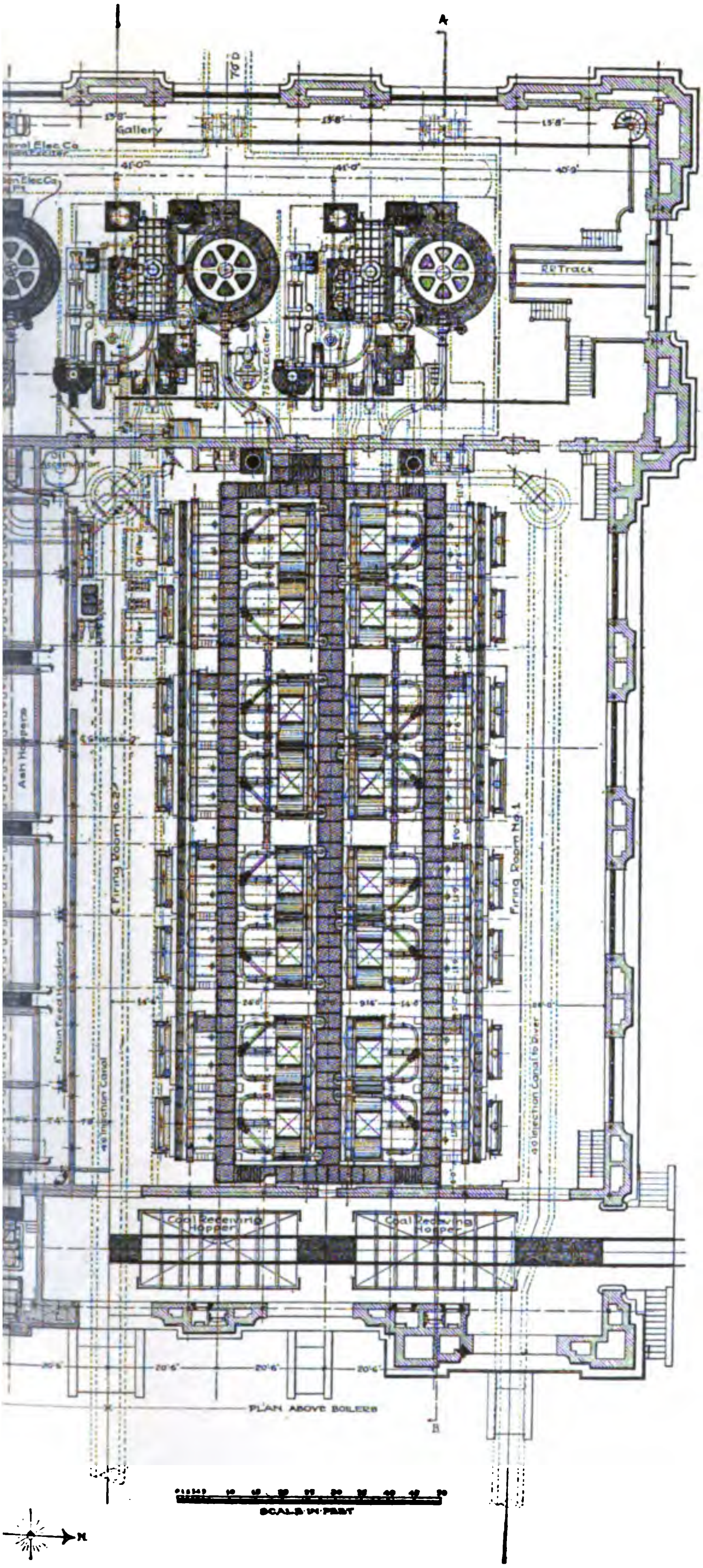


FIG. 5. General Plan of Fisk Street Plant, Chicago, showin

70' Discharge Canal to River



four 5000-K.W. Turbo-Generators (*Western Electrician*).

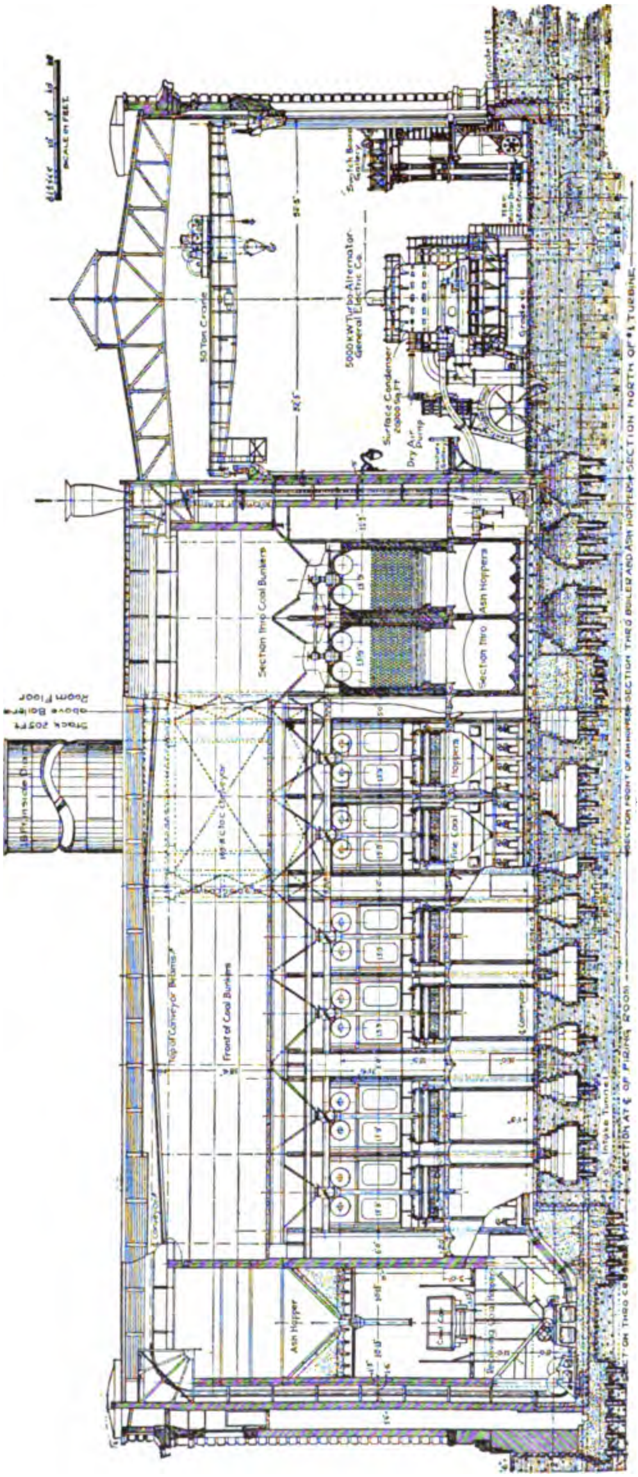


FIG. 6. Cross-Section, Fisk St. Plant, Chicago (*Western Electrician*).

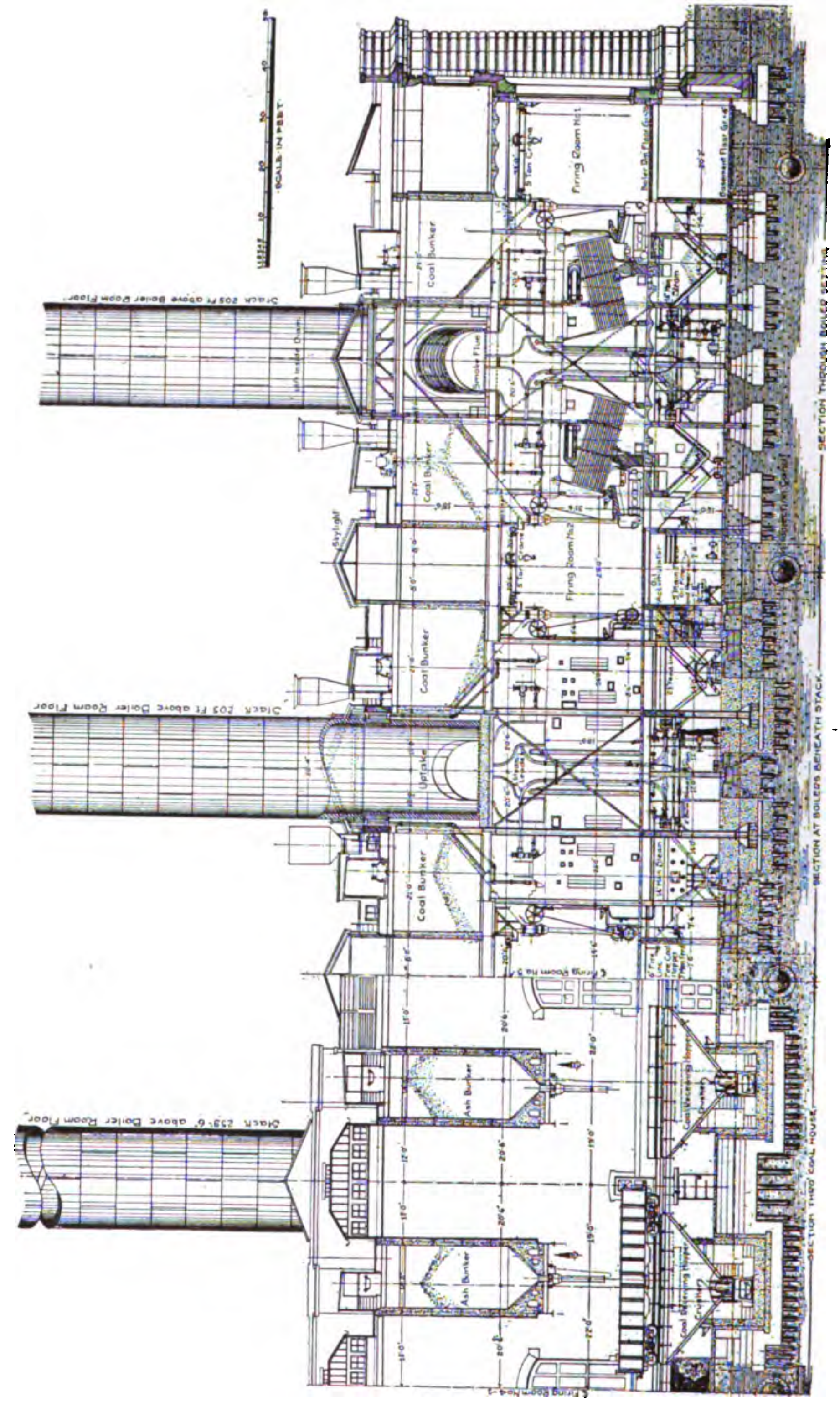


Fig. 7. Longitudinal Section through Boiler Room, Fisk St. Plant, Chicago (*Western Electrician*).

and a very efficient operation at 9,000 K.W., resulting in a normal rating at the latter capacity.

Condenser Plant, etc. — The condensers for the 5,000-K.W. units have a cooling surface of approximately 20,000 square feet each, and although they are comparatively high, being placed on the main generating-room floor, they occupy a large amount of space. This disadvantage, however, is practically overcome by placing the centrif-

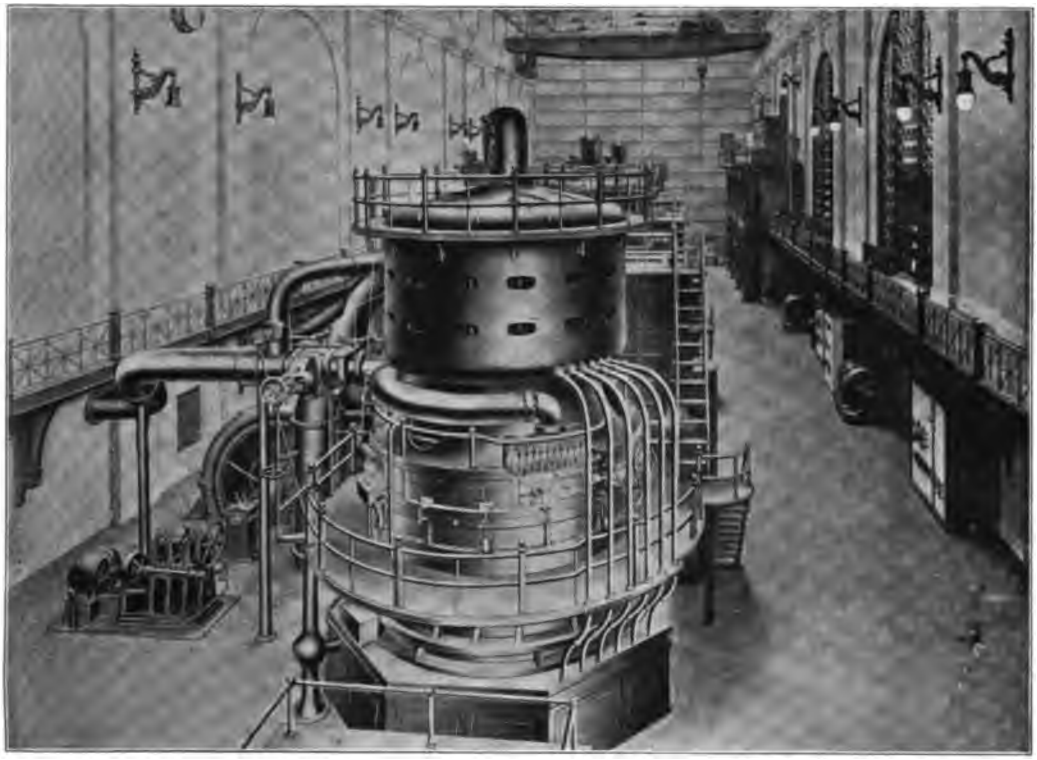


FIG. 8. Interior of Generating Room, Fisk St. Plant, Chicago.
5000-K.W. Curtis Turbine.

ugal and dry vacuum pumps, which are operated from a single engine, at right angles. At the side of the condenser are also placed the boiler feed pumps, which are of the single cylinder vertical pattern. For each boiler row of 5 boilers there are 2 feed pumps, each of sufficient capacity to take care of the entire boiler section.

The first and last turbines each have their own intake tunnel, the others being supplied in pairs. The 5,000-K.W. turbines have intake tunnels of 4 feet and 4 feet 6 inches in diameter, while the 9,000-K.W. units have intake tunnels of 5 feet in diameter. The water flows by gravity to suction wells, placed below the boiler house near the generating room. The suction line for the centrifugal pump of the 9,000-K.W. units is 42 inches in diameter; the discharge of the condenser is the same diameter. For the

four 5,000-K.W. units there is one discharge tunnel leading to the other side of the power house to the Allen Canal. There are a total of 7 intake and 3 discharge tunnels, drawing the water from one canal and discharging to the other.

The hot well pumps, which are of the centrifugal type, are submerged in an iron hot well some 4 feet 3 inches in diameter and 9 feet deep. The vertical motors are carried above the floor on the top of the hot well. Directly at the side, well grouped

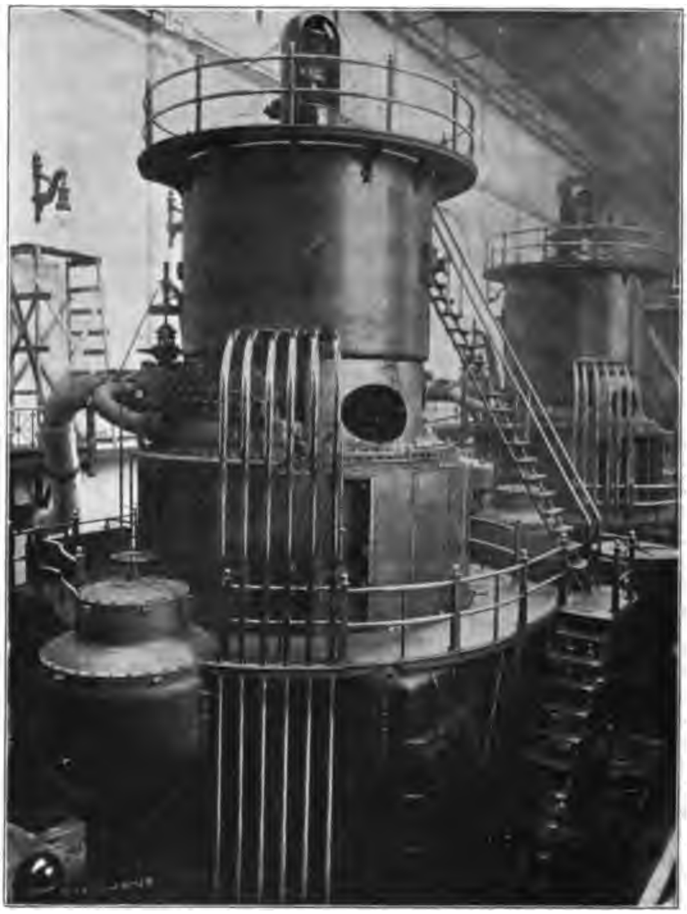


FIG. 9. 9000-K.W. Curtis Turbo-Generator, Fisk St. Plant, Chicago.

with the other apparatus of each turbo-generator set, is arranged one vertical cylindrical feed-water heater, some 18 feet high. Both heater and hot well are placed in a trench some 9 feet deep. Each turbine is provided with a separate 36-inch exhaust line leading beneath the generating-room floor to the boiler house, and then through the roof. Each line is provided with an atmospheric relief valve near the condenser.

Oiling System. — A large steam driven oil pump maintains the circulation of oil for the step bearings at 1,200 pounds per square inch. There are also installed for

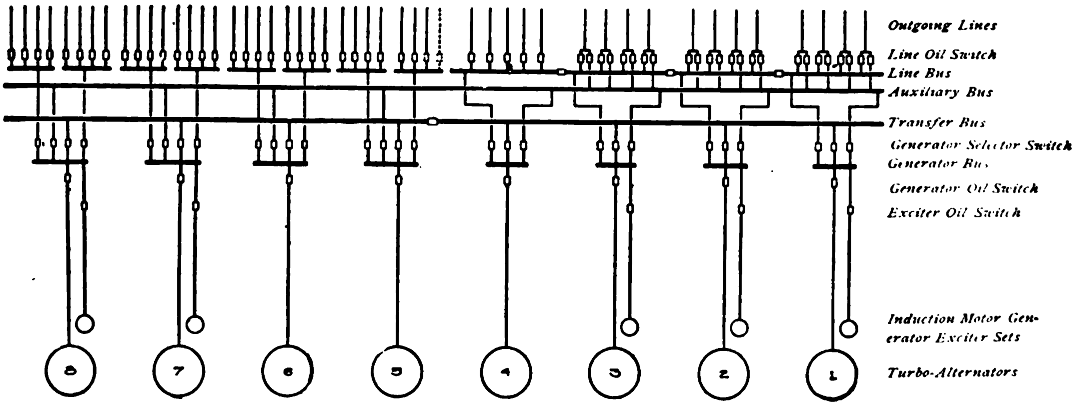


FIG. 10. Wiring Diagram, Fisk St. Plant, Chicago.

each turbine a motor driven triplex oil pump, and held in reserve, each having a capacity of 6 gallons per minute. Accumulators are placed in the boiler room to maintain a constant oil pressure in case of temporary disablement of the oil pumps. As usual, after passing through the bearings, the oil is filtered and used over again.

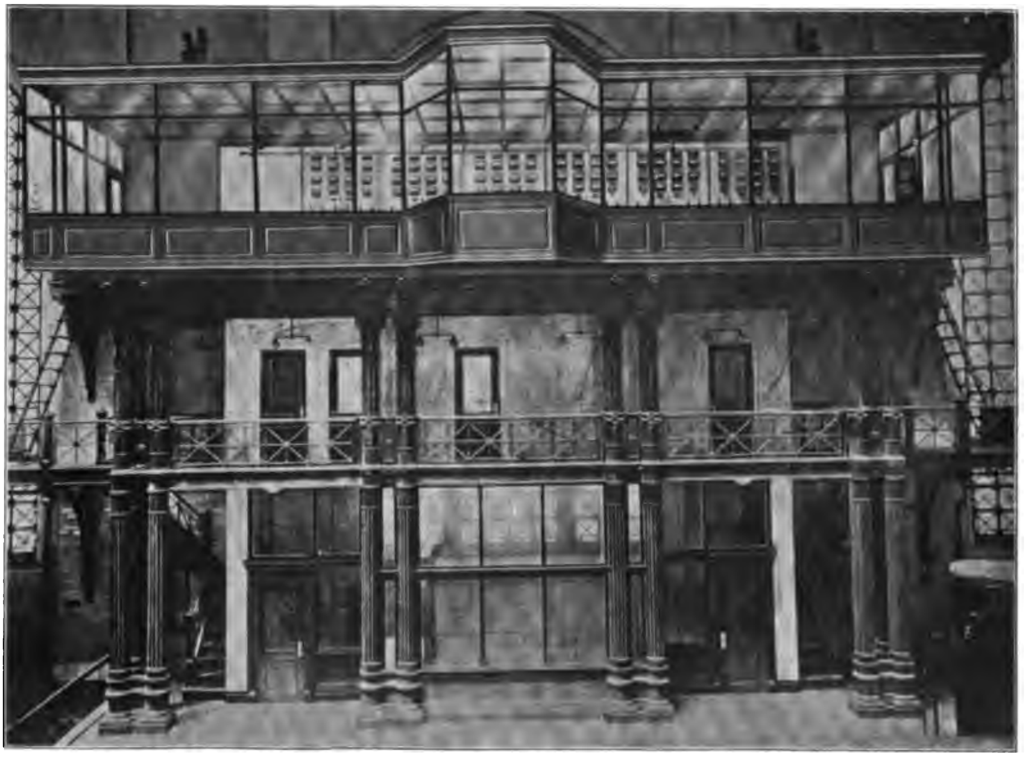


FIG. 11. Engineer's Office and Operating Gallery, Fisk Street Plant, Chicago.

Electrical Equipment. — The generators are of the 3-phase, 25-cycle, 9,000-volt revolving field type. As the plant is arranged on the unit system, the generators and other electrical apparatus are similarly arranged; provision, however, is made for the operation of the generators in multiple. The exciter current is taken from the main and auxiliary bus-bar.

There are at present installed three 50-K.W. motor generator sets for the four 5,000-K.W. units, while two similar units are proposed for the new 9,000-K.W. units. In

FIG. 12. Switches in Switching House, Fisk St. Plant, Chicago.

addition to these motor driven exciters there is a 75-K.W. steam driven exciter and a storage battery of 70 cells with a one-hour discharge rate of 800 amperes.

Switching Room. — As already stated, there is a separate two-story building for switching purposes 560 feet long by 50 feet wide, and 50 feet from the main building. The main bus-bars, high-tension connections, transformers, manholes, etc., are placed in the basement of this building, while the high-tension oil switches, instruments, etc., are on the first floor. The main oil switches are controlled from the generating room; centrally located in the main generator room, and above the visitors' gallery is a switchboard balcony. From here the entire generator room may be easily overlooked. Only

the instruments required for the operation of the plant are in the balcony, the overload releases, integrating wattmeters, transformers, etc., being in the switching room.

The main switchboard in the switching gallery is made up of panels 5 feet wide, there being one panel for each generator, with a wattmeter and ammeter in each of the four legs of the generator, a voltmeter, a power factor meter, a frequency indicator, a field ammeter, and exciter voltmeter mounted on each. In front of each panel is a controlling bench for operating the oil switches, provided with a dummy bus-bar system.

Advantages for Employees.—For the benefit of the employees, this plant has been provided with kitchen, refrigerating plant, etc., as follows:

In the second story of the switch house are locker rooms, wash rooms, lavatories and shower baths, for the attendants in the generating and switching rooms; a similar equipment has been provided in the basement of the boiler room for the boiler-house attendants, with good light and ventilation. In the switch building, second floor, there are provided bedrooms for the temporary use of those having special duties. Here are also a kitchen and dining room, where substantial meals may be had at small cost. All cooking, etc., is done by electricity.

At the side of the kitchen is a 200-pound refrigerating plant. Also on the same floor are an assembly and reading room, where all important engineering periodicals are on file, together with many books of reference.

It will be seen from this that much has been done for the comfort and convenience of the employees. This was the more necessary since there are no restaurants or boarding houses near by, and it is undoubtedly a paying policy to care for the employees in this manner. It may sometimes be difficult to secure a good operating force, but it is often still more difficult to keep it.

TWIN MUNICIPAL PLANT, VIENNA.

For supplying the City of Vienna with both light and power, and for operating railways, both in the city and suburbs, two power plants have been built on the Simmeriger Heide, the 11th District of the city, directly at the side of the Danube Canal and the Vienna Interurban Railway, from which sidings for the handling of coal and ashes have been run. On account of physical difficulties, two separate plants have been erected, one serving for light and power for the city and private customers, and the other for railroading. These plants were designed by the same engineers and were erected and put into operation at the same time; it is fortunate that the frequency of the generators of both plants was chosen the same, 96 cycles per second. At present the difficulties have entirely disappeared, and the two plants operate in parallel, so that current for light or power may be drawn from either of the two plants.

On account of the above-mentioned conditions it will be easily seen that not only the first cost, but also the operating expenses are materially increased.

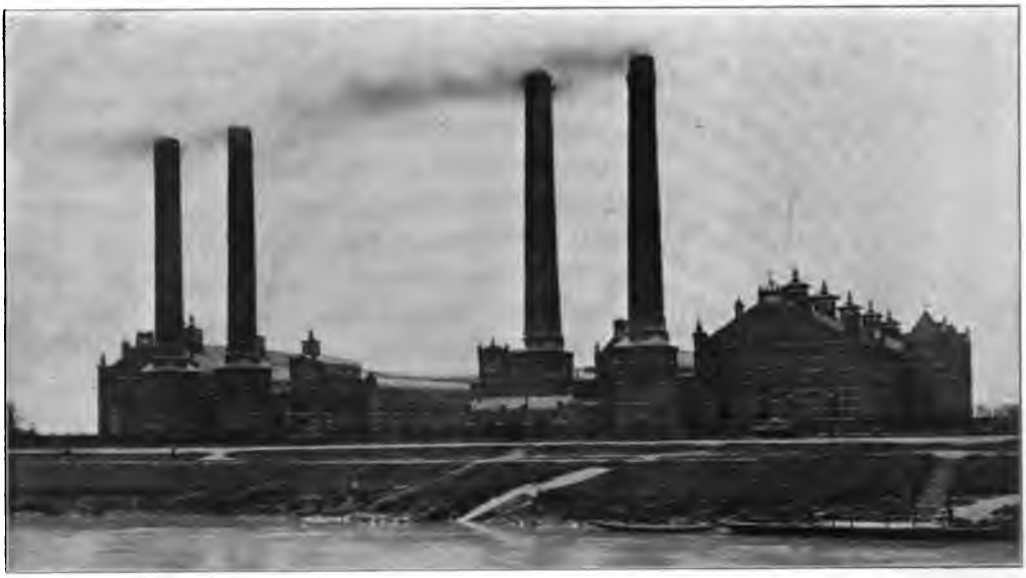


FIG. 1. Twin Municipal Plant of Vienna, Railway Plant at the Right.

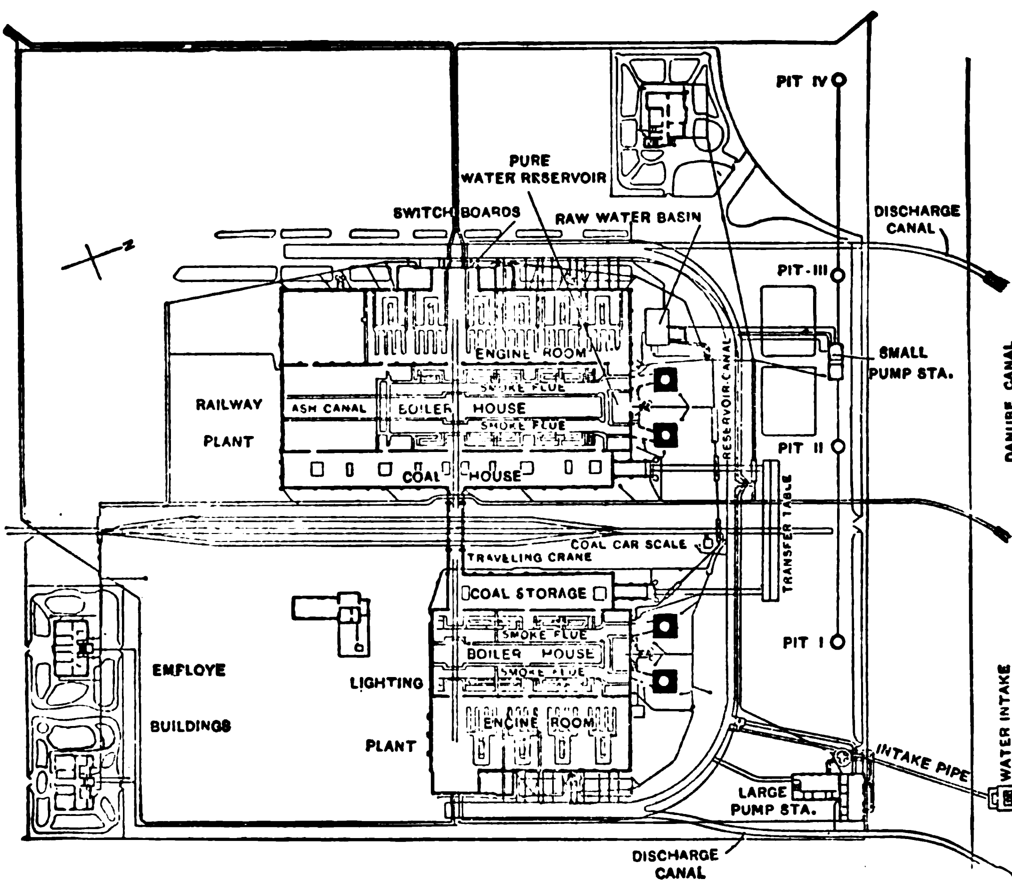


FIG. 2. General Plan of Twin Municipal Plant, Vienna (*Engineering Magazine*).

The railway plant is the larger and has been designed to accommodate eight 3,000-horse-power horizontal engines, of which five are at present installed, while the lighting plant has been designed to accommodate four units of the same type and capacity.

As will be seen from Fig. 1 both plants are placed side by side practically in the center of the plot and surrounded by a number of buildings; viz., one large pump station for condenser-water purpose and one small pump station for boiler feed, an office building for the superintendent and his staff, a superintendent's residence

FIG. 3. Transfer Table for Coal Cars, Vienna.

and a building for the main operating force. Further there is a canteen for the general staff, as the plant is practically isolated from the city.

As will be seen from the accompanying plan, the general arrangement of the two plants is identical, each having an enclosed coal storage building, boiler house, generating house and a switching house. The coal storage plants are almost side by side, being separated from one another only by the 3-track railroad siding referred to above. This arrangement was made to facilitate coal handling. The coal is brought in on cars on this siding, and carried to a transfer table running crosswise to either of the two plants, from where the cars are brought to the coal storage house. Both plants are surrounded on three sides by a condenser water tunnel in the shape of a horseshoe, and are fed directly from the Danube Canal, or by means of one of the pumping

stations. This tunnel is built to serve as a reservoir, as the water level of the Danube Canal varies so greatly that a storage of water was found to be necessary. As has been stated, the largest building is that known as the "railway plant," while the other one is known as the "lighting plant," but by an extension of these buildings, which will be found to be necessary in the near future, both plants, if desired, can be made of equal size. In order to give a still better water supply it is intended to run a condenser water tunnel around the whole plant, thus forming a ring.

For unloading machinery a structure adjoining the two buildings has been erected, overspanning the railroad sidings. A 20-ton electrically operated crane unloads the material from the railroad cars.

The buildings composing the plant are well grouped and well designed architecturally. In order to avoid dust as much as possible, they are surrounded by grass plots and gravel walks, while a number of shade trees are scattered throughout the lawns. A high picket fence encloses the whole. The entire appearance of the plant is most striking and is a very good example of European power plant practice.

Coal Handling System. — Coal cars of 15 to 20 tons capacity are conveyed to a 25-ton transfer table of special construction, which takes the cars to an additional siding, leading to the elevating tower of the coal storage building. The transfer table receives the car from one side only and has a platform of 6 wheels over 3 rails, which are on the same level as the main tracks, from which the car is received, thus doing away with the usual pit, and leaving the main track uninterrupted. The cars are drawn up the slight incline of the platform by a 10-horse-power, 300-volt, 3-phase synchronous motor. This motor also serves to propel the platform to the required destination, either to the tracks leading to the coal storage building of the railway plant or the lighting plant. The cars, after entering the coal storage building, are elevated by a 300-volt, 35-horse-power, 3-phase synchronous motor in a tower above the track bins. The elevation of the coal cars requires two minutes, and after a car has reached the proper height an automatic brake is applied. A second brake will act in case the first should fail. From the platform of the elevator the cars run over a steel frame structure some 20 feet above the coal bins, the columns of which are protected by wooden covering which, at the same time, serves as a part of the compartment partitions. There are 10 compartments or bins in which the coal is dumped according to grade. The storage capacity is sufficient for about six weeks. Coal is conveyed to the boilers in small three-wheel cars of half a ton capacity, filled and moved by hand and automatically weighed while being conveyed to the boiler, where the firing is done by hand. This method, while not the most recent or modern, is considered the cleanest and most economical. The cost of labor is considerably increased by this plan, but as each car of coal is weighed and close track is kept of the ability of the stokers, the result is that eventually this system is found to be economical. The same arrangement applies to both railway and lighting plants.

Condenser Water Supply. — As already mentioned, the water supply for the railway plant, as well as the lighting plant, is very elaborate. Owing to the fact that the

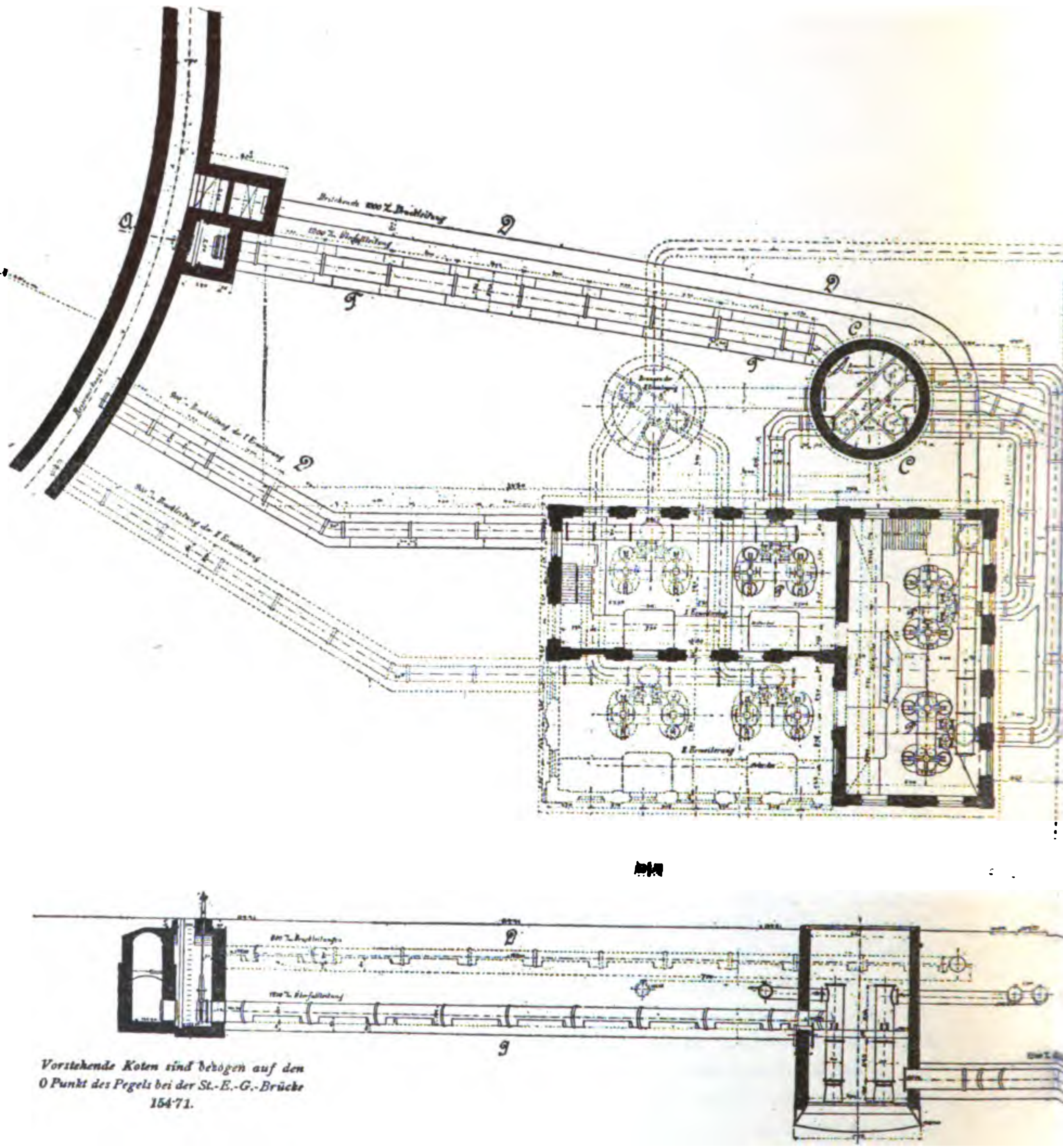
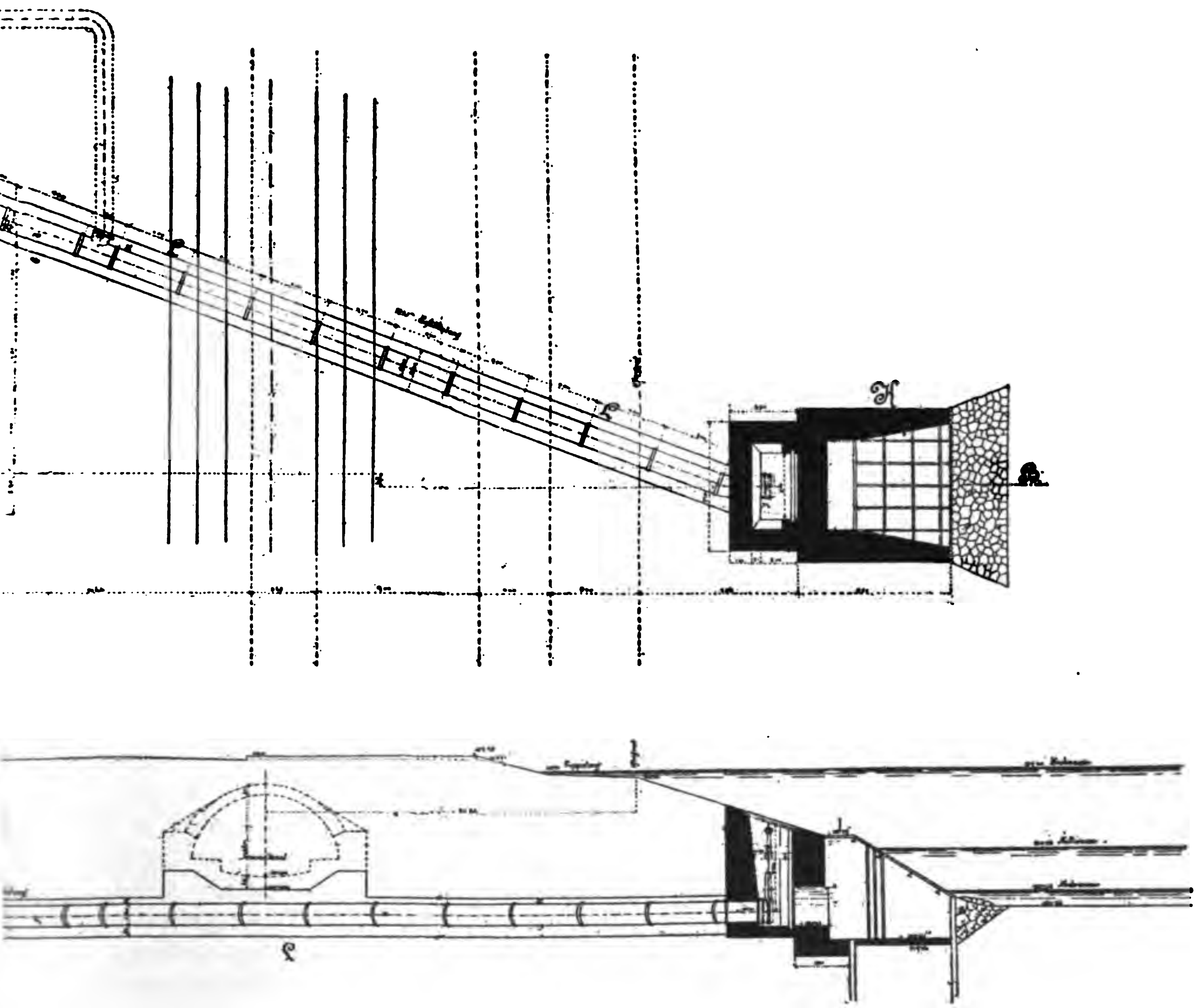


Fig. 4. Condenser Water Supply



ystem, Municipal Plant, Vienna.

water level of the Danube Canal varies, in winter falling some 9 feet below and in the rainy seasons rising some 12 feet above the mean water level, it will be seen that it was necessary to make provision to meet these conditions.

In order to be sure of an uninterrupted operation of both plants, irrespective of unfavorable water supply, one large pumping station for elevating the water from the Danube Canal into the reservoir tunnel was installed. For supplying boiler feed water a small pumping station has been erected and four wells have been driven.

The accompanying plan shows the condenser water supply system. Referring to the lettering in this plan, the screen chamber "K" is set in the bank of the Danube

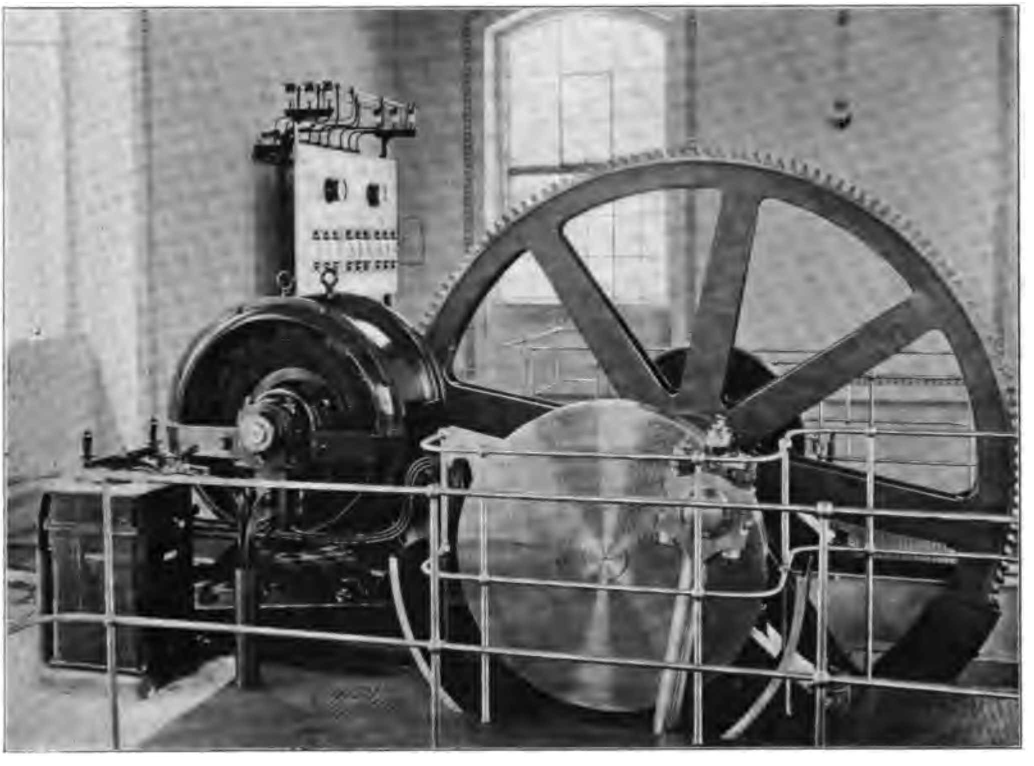


FIG. 5. Motor Drive for Condenser Water Supply Pumps, Vienna.

Canal, the bottom of which is about four feet below the canal bed. This was done in order to maintain a practically even water flow throughout the intake pipe. The intake chamber, which is of concrete, is some 23 feet in length, 16.5 feet wide and 18.7 feet deep, and the entire screen is below the high-water level. After the water has passed the rough or outside screen it has to pass a fine screen in order to enter the second chamber, whence it enters the supply pipe. The latter is 48 inches diameter and is fitted with a sluice gate. From here the water is let into the main well "C," from which it may run directly into the reservoir tunnel through the pipe "T," in which case, however, the water level of the Danube Canal is to be above that of pipe

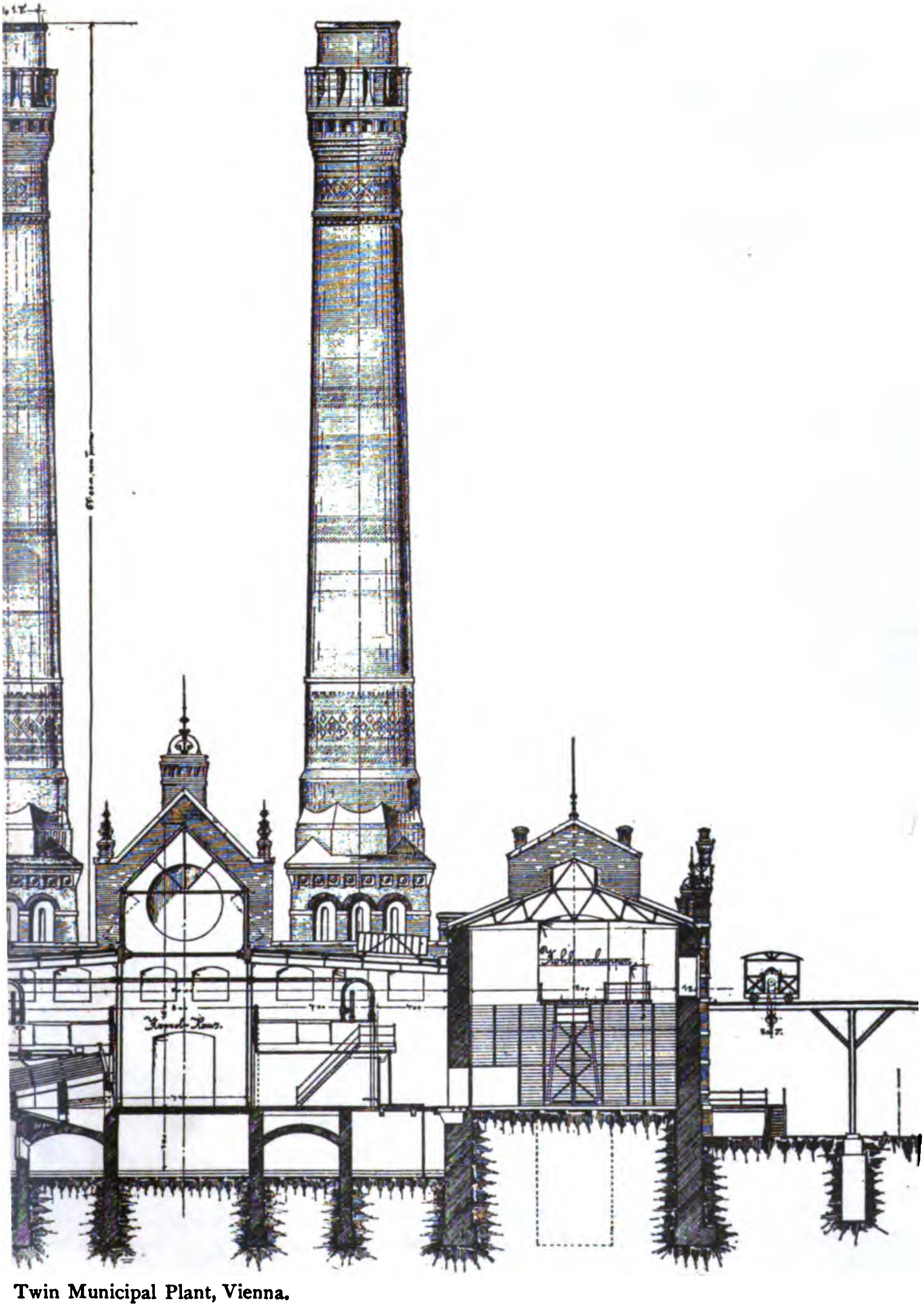
"T." When, however, the water level in the canal is below this point, pumps "P," in the large pump station on the side of this well, have to elevate the water. The present pumping station is designed to accommodate four pumps, only three of which are in place at the present time. In case of further increase in the capacity of the power plants it will be necessary to increase the pumping station by two more units. For

FIG. 6. Condenser Water Supply Pumps, Vienna (*Engineering Magazine*).

this purpose a well similar to "C" must be installed, as will be seen in the accompanying plan.

Each pump has a capacity of 865 United States gallons per second and is capable of lifting water 23 feet high, which will easily overcome the most unfavorable condition which may arise. The present pumps have a total capacity of 2,595 United States gallons per second, or about 30 per cent more than is required for the present plant, and it will be seen that a sufficient storage of water is obtained by means of the reser-

FIG. 7. Railway Station of the T



Twin Municipal Plant, Vienna.

voir tunnel. The pumps are of the vertical, 4-plunger, single-acting type, 18 inches in diameter, having a stroke of 24 inches, and making 60 revolutions per minute. Two plungers operate from a single crossbeam which is driven by a 75-horse-power, 3-phase motor. In order to do its own priming the pump is provided with an additional small vacuum cylinder, operated from the main levers.

While the pumps are located in the basement of the station, the motor is on the main operating floor. By means of a rheostat the speed may be reduced from 60 to 40 R.P.M.

The reservoir tunnel has a width of 6 feet and a depth of 16½ feet, and when both plants are completed this tunnel will have a total length of 2,300 feet, and will hold 1,663,000 United States gallons.

Boiler Feed-Water Supply. — As, at the time of the erection of this plant, the sewage system of the city was discharged into the Danube Canal above the power plants, the water was unfit for boiler feed purposes, and as the city authorities would not allow water to be drawn from the city mains beyond a certain quantity, wells were driven so as to give an adequate supply. This water, however, had to be softened, as will be seen later on. There are four wells, situated some distance from the canal, and from these the water is drawn by means of pumps in a small pump station. In this station are installed two motor driven rotary piston pumps, having a total capacity of 450 gallons per second. From here the water is pumped to the river water basin near the boiler house, whence it is pumped to a water-purifying system. This river water basin may also collect the condenser water discharge, in case the boiler feed-water supply should fail. This source of supply, however, cannot be taken advantage of under present conditions, and not until such time as the sewage discharge is placed below the condenser water intake.

The water supply systems herein described apply (as did the coal handling system) to the lighting plant as well as to the railway plant.

As both plants have been designed on the same lines, it will suffice to describe the railway plant only, the only noticeable difference between the two being that the lighting plant contains fewer units.

Railway Power Plant. — This plant consists of a coal storage room, a boiler room, a generating room and an annex for switching purposes, etc. There are, in fact, four different buildings separated by partitions. With the exception of the switching room, which is 165 feet long by 30 feet wide, all three buildings have the same length, *i.e.*, 510 feet. The width of the coal storage room is 50 feet, that of the boiler room 100 feet, and that of the generating room 85 feet.

The appearance of the plant, and especially that of the generating room, is of pleasing effect. As may be seen in the accompanying illustration the floor is tiled, while the light and ventilation are well taken care of, there being a number of roof ventilators (small towers) as well as large windows throughout the building.

Boiler Room. — The boilers are banked on each side of a wide aisle, arranged two to a battery, there being at present 20 boilers of the Babcock & Wilcox pattern, made

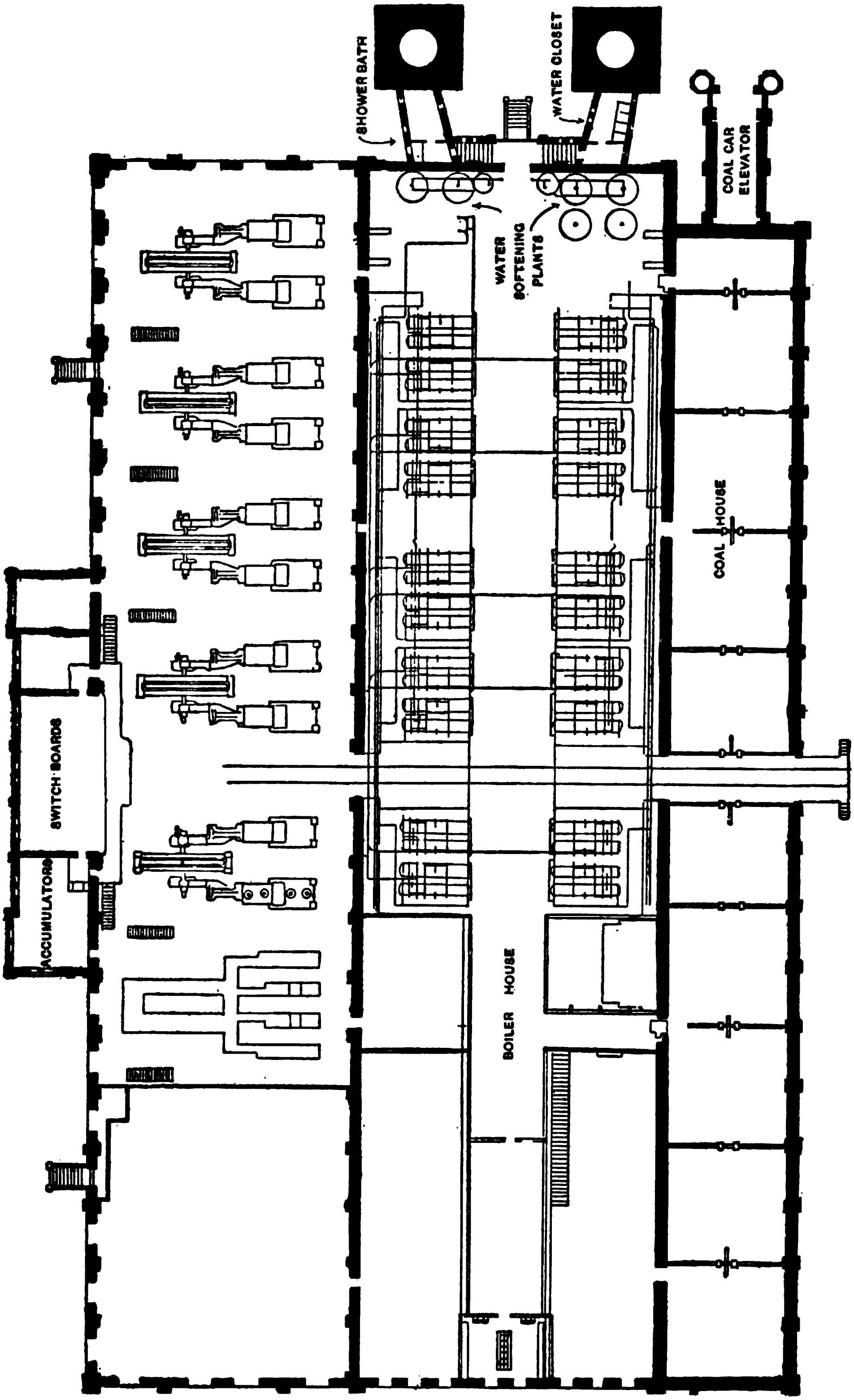


FIG. 8. Railway Plant of the Vienna Municipal Installation (*Engineering Magazine*).

by the " Ersten Bruenner Maschinen Fabrik," Austria. They are each of 3,075 square feet heating surface, and operated at a pressure of 215 lbs. per square inch. Four of these boilers supply steam to one 3,000-horse-power engine. Each boiler consists of two drums 23 feet long, 42 inches dia. and 14 × 8 tubes. The lower horizontal headers, consisting of 22 tubes, are connected to the vertical headers by means of short tubes, while four longer ones connect each header directly to the boiler drum. This is done to increase the circulation of water in the lower row of tubes. In addition, in each boiler drum is installed a Dubian artificial circulating apparatus, by which the generation of

FIG. 9. Interior of Boiler Room, Vienna (*Electrical Review*).

steam is increased, it is claimed, from 3 pounds per square foot heating surface to 4 pounds and higher. Steam and water passing up through the headers with great velocity pass through the vertical tubes of the system, which project above the high-water level in the drum, thus greatly accelerating the circulation and evaporation. It will be noticed that these boilers are not equipped with a mud drum, although two 2½-inch blow-off pipes are provided at the vertical header, a practice which is commonly found in Europe where water-purifying systems are installed. Between the water tubes and the drums is arranged a superheater of 575 square feet, which will increase the steam temperature to 570° Fahr. The boilers are equipped with hand-fired grates of 87.5 square feet surface, while above the fire doors steam jets are provided for better smoke

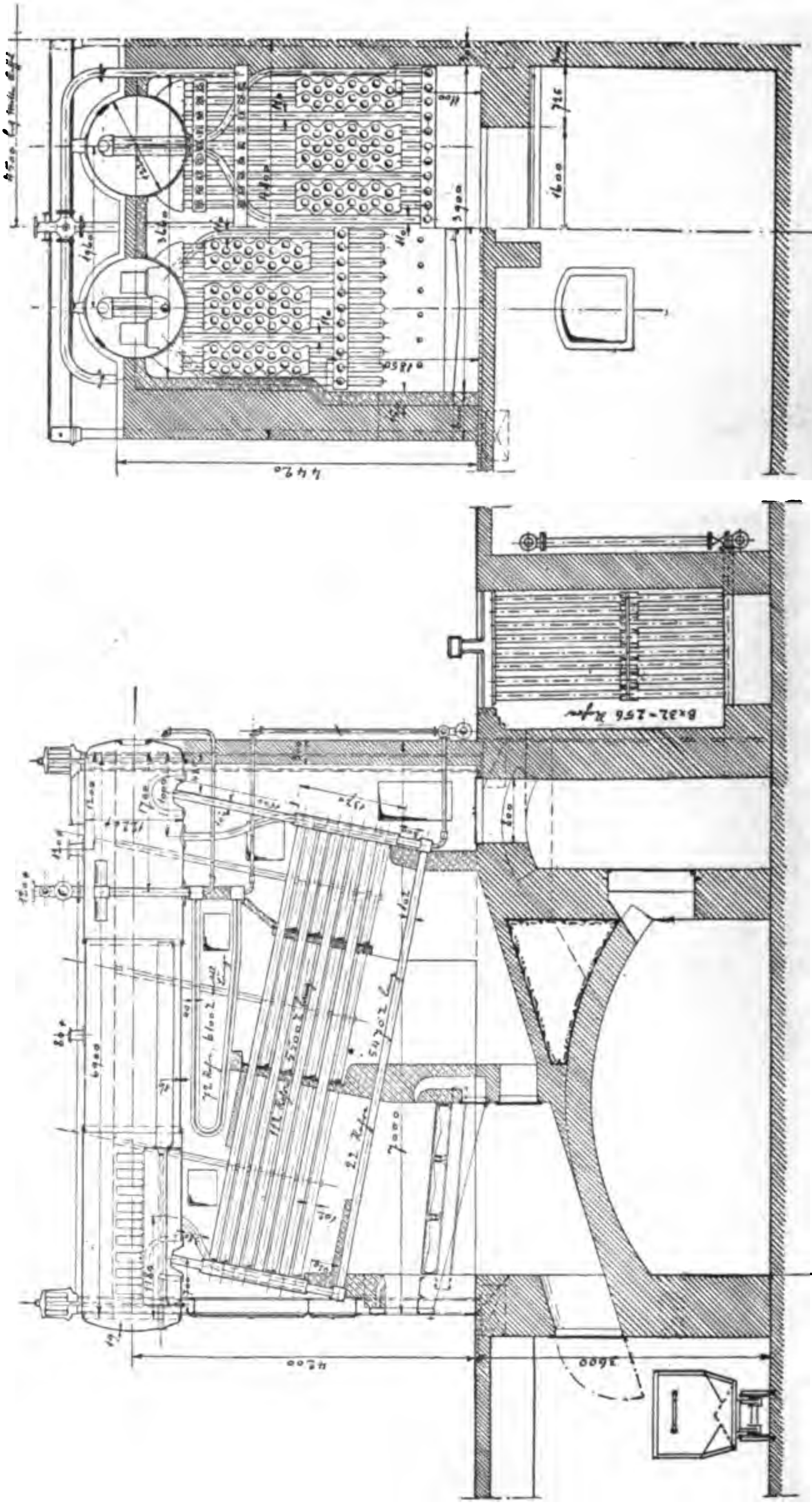


FIG. 10. Boiler and Economizer, Municipal Plant, Vienna.

consumption. In addition to this the fire wall is provided with air ducts admitting air from the ash pit directly above the furnace.

The ash and soot pits are of brickwork, the fire bridge being provided with suitable openings equipped with sliding doors.

Feed Water. — In the rear of the boiler in the basement, Green economizers are installed. The cleaning of the tubes is accomplished by electrically operated scrapers. For every two boilers (or battery) there is installed one economizer. The temperature of the water in the economizer is raised to 212° Fahr.

Four Worthington compound boiler feed pumps, working upon a ring pipe system,

FIG. 11. Reisert Water Purifiers, 28,000 cu. ft. hourly capacity, Municipal Railway Plant, Vienna.

furnish the necessary water. The pipes are arranged so as to easily by-pass the economizer and feed directly into the boilers. In order to do so, however, the water is previously heated by the exhaust steam of the boiler feed pumps. The hot-water storage tank, containing a set of coils, is located on the boiler-room floor.

At one end of the boiler house are installed two water purifiers. They are of the Hans Reisert system and have an hourly capacity of 1,050 United States gallons. The river water is taken out of a reservoir in the basement and pumped by means of two Voith compound pumps into a tank above the purifying plants. After the water has

been softened in the purifiers to 5 English degrees it is collected in the above-mentioned hot-water tank on the boiler-room floor.

Chimneys. —At the end of the plant are two chimneys with ornamental brickwork. The internal diameter at the top is 12.5 feet; the height is 205 feet above the furnace. For a height of 30 feet the chimneys are lined with fire brick. The foundations are of hydraulic concrete mixed 1:3:7, while the lowest layer is a mixture of 1:3:5. This mat has a thickness of 4.7 feet and is 49.2 square feet in area, reinforced by a grillage of "I" beams. The entire weight of the chimney, which is of radial brick, with the exception of the base, is 3,800 long tons, 1,450 tons of which is the weight of the foundation.

Steam Piping.— A 5-inch pipe, which is provided with a non-return valve, leads from each boiler or superheater. As four boilers supply steam to one engine, these pipes are connected to one main header 8 inches in diameter. These pipes are of Mannesmann process, long sweep bends taking up the expansion and contraction. The main header, which is suspended from the building structure, leads toward the division wall of the boiler and generating room, where it runs down below the boiler-room floor in the basement and thence to the engine. This latter end of the steam pipe is increased to a diameter of 18 inches, in order to act as a small reservoir, which is necessary on account of the small steam pipe. Before the pipe is connected to the valve chest of the cylinders a small separator is provided for the purpose of drawing off any water which might be present. The tongue and groove joint system of flanges has been adopted throughout the entire plant. In order to insure safe operation the adjacent steam headers are interconnected. All high-pressure pipes are covered with Thermalite, a very efficient insulating material.

Engines. — There are at present five 3,000-H.P. engines installed, manufactured by the "Ersten Bruenner Maschinen Fabrik" after the pattern of the well-known Sulzer Bros. These engines are of the four-cylinder, triple-expansion, vertical type, developing at 175 pounds pressure, 90 revolutions per minute, 3,000 normal H.P. or 3,600 maximum I.H.P. The engine is made up of one high-pressure cylinder 31.5 inches in diameter, one intermediate cylinder of 46 inches diameter and two low-pressure cylinders each of 68 inches in diameter, the common stroke being 59 inches. As the cylinders are arranged in tandem form, the two low-pressure cylinders are nearest the shaft. This is done to prevent the unnecessary heating of the generator by the high-pressure steam cylinder. The cylinders are arranged on a bedplate to allow for expansion, which amounts at the end of the high-pressure cylinders to $\frac{3}{8}$ of an inch. All cylinders, with the exception of the high-pressure cylinders, are steam jacketed.

Each cylinder is provided with 4 four-seated poppet valves and the entering steam is controlled by a Sulzer governor, of such delicacy that by throwing off the entire load the variation in speed is only 4 per cent. For the purpose of throwing the different

generators in parallel these governors are equipped with small electric motors operated from the switchboard.

The cranks are placed at 108°. The poppet valves are operated by bevel gears provided with expansion couplings. Each cylinder is provided with an oil pump, while for oiling the crank pins, cross-headers, etc., a central oiling system is used. Beneath each crank in the basement is placed a wet jet condenser outfit. The pumps are operated by means of a rocker and hollow rod from the main crank pins. The stuffing boxes of the pumps are water sealed in order to maintain a good vacuum. The engines

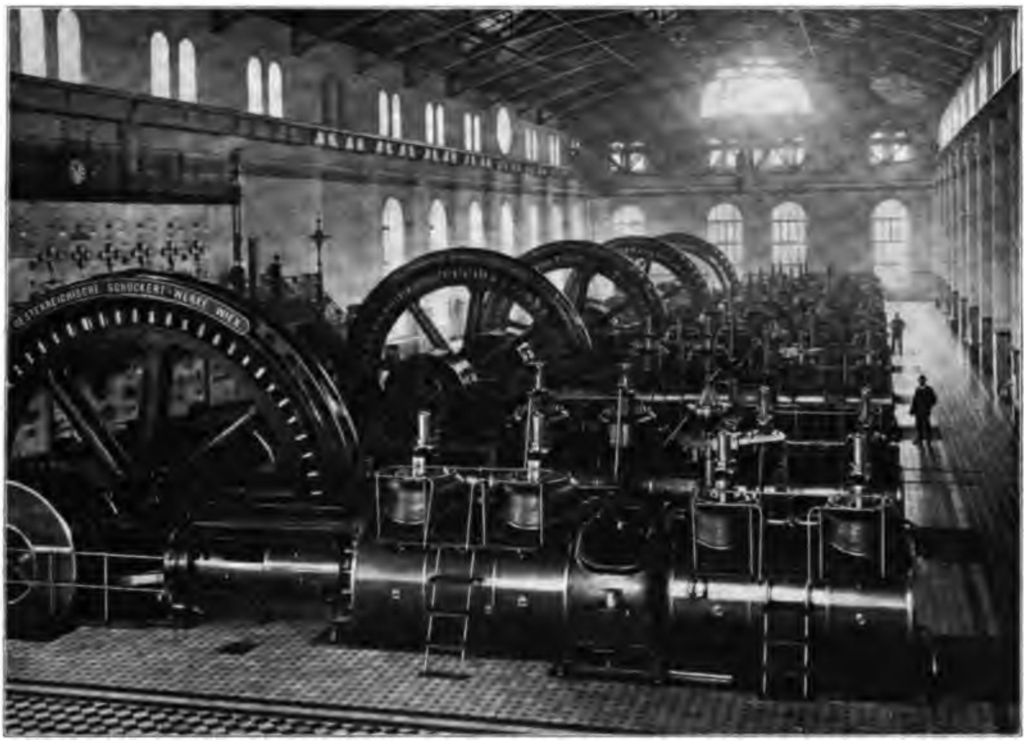


FIG. 12. Generating Room, Vienna Plant.

are guaranteed at a pressure of 175 pounds with a steam temperature of from 500° to 575° Fahr. to consume not more than 10 pounds per I.H.P. hour. The weight of each engine without generator is 245 long tons and its cost 250,000 kronen or $50,000. The foundation of each unit consists of 1,040 cubic yards concrete and costs 41,000 kronen or $8,200.

Generators.—Between the cylinders upon the shaft is mounted a 2,000-K.W. 3-phase generator. The stationary part is made up of 4 cast-iron pieces, each 28.8 feet in diameter, 31 inches wide. The magnetic field is provided with 384 slots and for properly insulating the coils, mica tubes are used. The rotating part of the gen-

erator weighs 43 long tons. The fields are excited by 220-volt direct current. At 90 revolutions per minute the frequency is 96. The voltage is 5,500, normal load 2,000 K.W., while 2,500 K.W. may easily be developed.

Exciters. — In the front of the switchboard there are at present three 220-volt exciter generators, direct connected to 5,500-volt, 3-phase motors. Each set has a capacity of 65 K.W., which will suffice to excite two of the main generators. So as to insure a

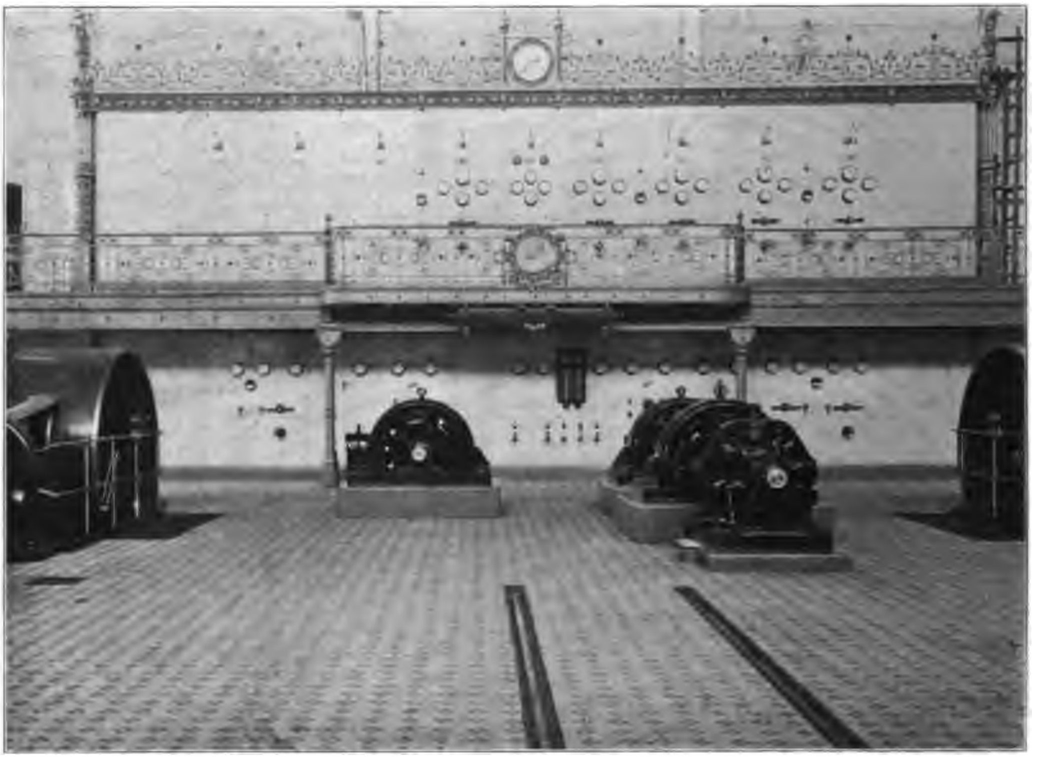


FIG. 13. Switchboard and Exciter Units, Vienna.

safe operation in case of emergency and to allow for fluctuation in the load a storage battery is installed.

Crane, etc. — The generating room is equipped with a 40-ton electrically operated crane, with a span of 84.6 feet. The trolleys are provided with three motors, 8, 11 and 15 H.P. In place of the wire cables usually employed in connection with a crane, a Gall's chain is used. The movement of the crane is 50 feet per minute, while that of the trolley is 30 feet per minute. A load of 20 tons may be hoisted 3.3 feet per minute, while 40 tons (or a full load) requires double that time. The crane body itself is a lattice girder design, which is much favored on the Continent of Europe.

Switchboard. — The switchboard is of ornamental design and separates the switching building from the main generating room. This switching building consists of

several floors and contains, besides the rooms occupied by the electric equipment, a measuring room, a storage room, repair shop and offices. The space occupied by electric equipment is divided into three sections for three separate purposes, one to contain the generator leads, one the outgoing feeders, while the third is used for the exciter current. Sections 1 and 2 contain two bus-bar systems, so arranged that all generators may be thrown in parallel on the outgoing feeders. Between the generator

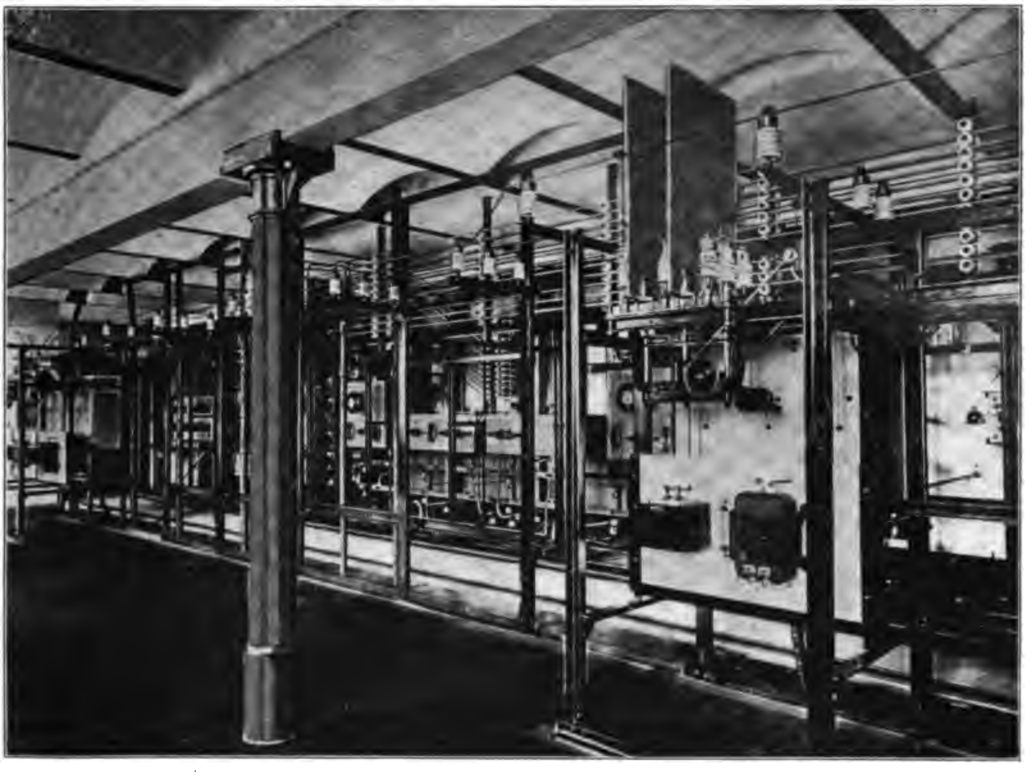


FIG. 14. Rear of Switchboard on Main Generating Floor, Vienna.

leads are installed sectional lighting switches. The switchboard itself, according to European practice, is faced with marble slabs mounted upon an iron structure. It is two stories high. The apparatus required for each generator and outgoing feeder has its own panels. Such a panel consists of a voltmeter, ammeter and recording wattmeter, high-tension switches and fuses, and further necessary equipment for exciter current and synchronizing the generator. The upper part of the switchboard, which is served from the gallery in front of it, is for the outgoing feeders exclusively. For operating the various pumps, cranes, etc., two transformer groups are installed in the basement of the switching building, near which the storage battery is placed. The transformers are of the oil-cooled types, 150 K.W. and will reduce the voltage from 5,500 volts to 300; two other small transformer groups reducing the voltage to

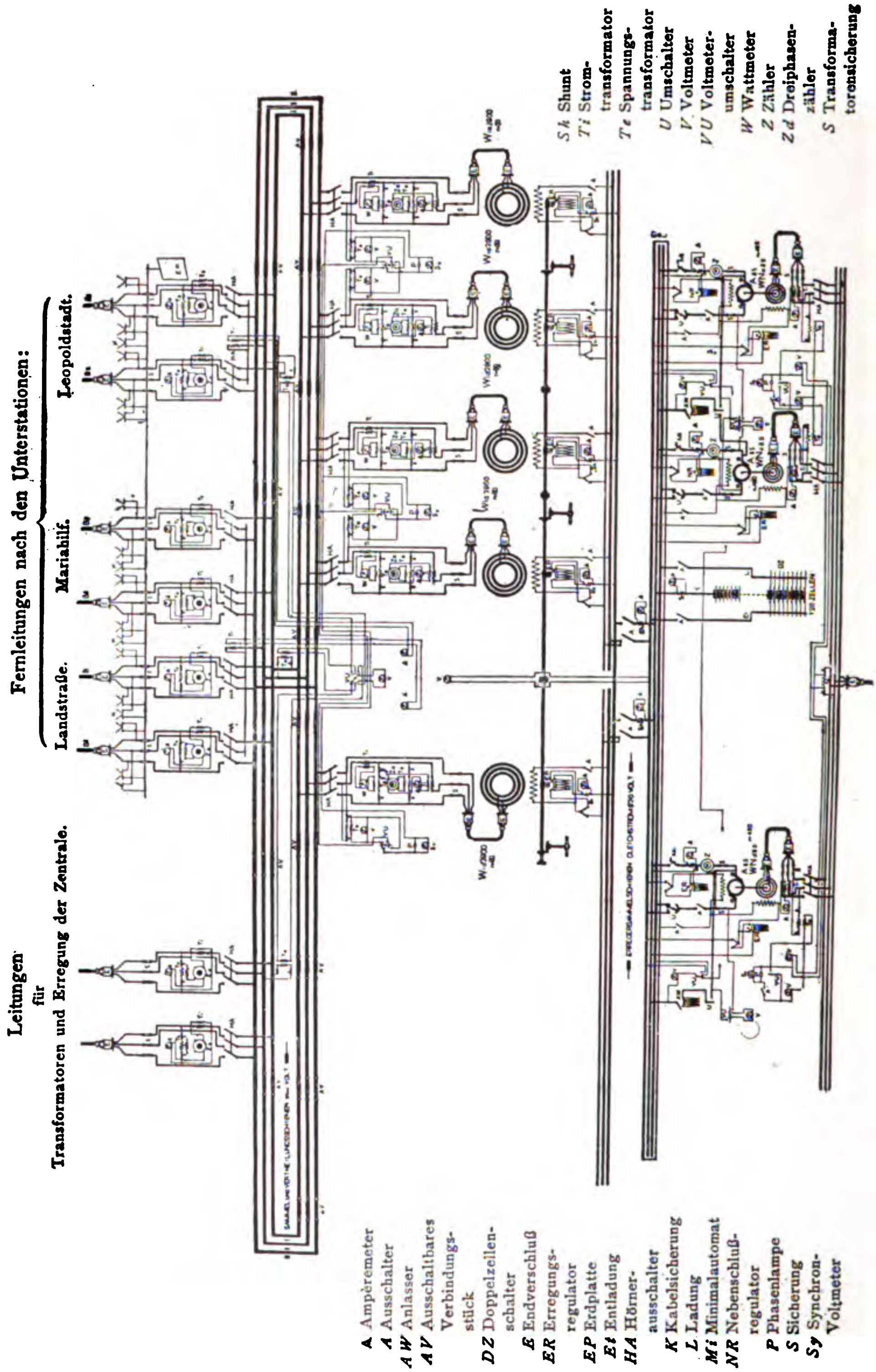


FIG. 15. Wiring Diagram of the Railway Plant, Vienna.

110 serve for lighting. In case of the failure of the 3-phase current arrangement, provision is made for lighting by direct current from the storage battery.

Tests.—The operation of this plant, as well as that of the lighting plant, is a most economical one. The operating results of these plants are given in the accompanying table, showing the manufacturers' guarantee, and the operation of the generating unit of the railroad power plant, with its boilers, etc., as well as that of the generator unit No. 2 of the lighting plant.

It will be noticed that the steam consumption in the latter plant is 9.4 pounds per I.H.P. hour, while the coal consumption is 1.3 pounds. Especial attention should be called to the fact that the total heating value of the coal for producing 1 horse-power hour amounts only to 16,093 B.T.U. The cost of producing one K.W. hour at the bus-bar is 0.36 (1.8 heller), the above-mentioned coal costing $3.60 (18 kronen) per long ton. This economical result, frequently obtained in European power plants, is not only due to the manufacturers' guarantee or the efficiency of the operating force, but also, to a large extent, to the wise selection and proper arrangement of the machinery to be used, on the part of the power plant designer.

TABLE OF GUARANTEE AND TESTS OF THE RAILWAY AND LIGHTING PLANTS OF VIENNA.

Subject.	Guaranteed Results by the Builders.	Actual Results of Test of Engine Units.	
		No. 4 of Railway Plant.	No. 2 of Lighting Plant.
Evaporation of water per sq. ft. heating surface per hour, in lbs.	3	3.45	3.30
Evaporation of water per lbs. of coal from feed water at 32° Fahr. in lbs.	7.1	7.50	7.5
Total efficiency of boiler in per cent	70	71.80	72.80
Calorific value of coal per lb. in B.T.U.	11,697	12,137	12,177
Efficiency of economizer in per cent	—	7.60	8.30
Efficiency of superheater in per cent	—	4.80	4.80
Indicated horse-power of steam engine	—	3,320	3,388
Output of generator, excl. exciter, in K.W.	2,000	2,091	2,086
Efficiency of generator unit in per cent	82.7	85.6	83.7
* Steam consumption per one H.P. hour in lbs.	10.1	10.1	9.41
Coal consumption per one H.P. hour in lbs.	—	1.43	1.32
Coal consumption per K.W. hour in lbs.	2.42	2.28	2.11
Coal consumption per K.W. hour in B.T.U.	12,870	12,584	11,723
Overload of generator in K.W.	2,500	2,600	2,550

* Steam pressure 175 lb., temperature 570° Fahr. (at throttle).

CHAPTER XI.

THE following tables show the principal dimensions and other data of turbine and reciprocating engine plants. The sizes and capacity of these plants vary from 4,000 K.W. to 60,000 K.W.; the sizes of the individual prime movers vary from 2,000 K.W. to 5,000 K.W. It is the author's opinion that it is not necessary to give data on smaller sizes of plants, as Chapter IX has been devoted to this subject. There are also a series of tables on the equipment of plants per K.W. These figures vary and it will be seen cannot be blindly followed, but comparison may be made and conclusions drawn therefrom.

Between the various tables illustrations are inserted which speak for themselves.

Subject.		Remarks.
Building	. . . .	Hollow concrete blocks.
Boiler room	164′ × 120′	Two firing aisles.
Generating room	164′ × 45′	At right angle to boiler room.
Switching room	164′ × 15′	Annex.
Boilers	24 B. & W.	. . . .
At present installed	16	In four rows.
Size	6,040 sq. ft.	. . . .
Pressure	175 lbs.	. . . .
Superheat	1,185 sq. ft.	150° Fahr.
Grates	111.8 sq. ft.	Roney stokers.
Steam Piping	7″ at boiler, 15″ header	6″ auxiliary header.
Feeder Water Heaters (2)	Open type	. . . .
Capacity each	200,000 lbs. from 80° to 205° Fahr.	Per hour.
Feed Pumps (2)	16″ × 10½″ × 16″	Horizontal duplex.
" " (1)	16″ × 10½″ × 16″	Future.
Storage Tanks (2)	25,000 lbs. each	. . . .
House Pumps (2)	7½″ × 10″ × 10″	Horizontal duplex.
Chimney (3)	Concrete steel	One for 8 boilers.
Height above grate	183′ 0″	. . . .
Internal diameter at top	12′ 0″	. . . .
Coal Handling	1 locomotive crane	Steam driven.
Conveyors	2 bucket and 2 belt conveyors	15 horse-power motor per set.
Capacity each	40 tons per hour	Crushers, 25 horse-power each.
Bunkers (2)	650 tons	6 tons per lineal ft.
Ash Handling	Industrial railway	To bucket conveyor; reinforced concrete hoppers.
Circulating Water.		
Intake	40 sq. ft.	Concrete, part of turbine foundations.
Outlet	40 sq. ft.	
Turbo-Generators (2)	2,000 K.W. each	G. E. Co. Curtis.
" " (2)	5,000 K.W. each	. . . .
" " (1)	5,000 K.W. each	Future.
Speed	750 R.P.M.	. . . .
Generators	3-phase, 25-cycle	4 poles.
Volt	6,600	. . . .
Condensers	Base condensers	. . . .
Size	5,000 K.W. = 20,000 sq. ft.	. . . .
"	2,000 K.W. = 8,000 "	. . . .
Circulating Pumps	5,000 K.W. = 24-inch centrifugal	Steam driven, horizontal.
" "	2,000 K.W. = 16-inch "	" " "
Dry Vacuum Pump	Rotative, single-stage	" " "
Hot Well Pump	Two-stage, centrifugal	Motor driven, vertical.
Exciters (2)	100 K.W., 125 volts.	Steam driven, horizontal.
Oil Pumps (3)	9″ × 3⅜″ × 10″	Horizontal.
" " (1)	9″ × 3⅜″ × 10″	Future.
" " (1)	6″ × 4″ × 6″	Auxiliary pump.
" " (1)	6″ × 4″ × 6″	Future.
Tanks (2)	filtering tanks	600 gal. per hour, each.
Crane (1)	50 ton (10 ton aux. hoist)	50 feet above generator floor.
Span	43′ 0″	. . . .

FIG. 1. 5000-K.W. Turbo-Generator, Condenser Plant and Heaters, L St. Plant, Boston.

FIG. 2. Interior of Boiler Room, L St. Plant, Boston.

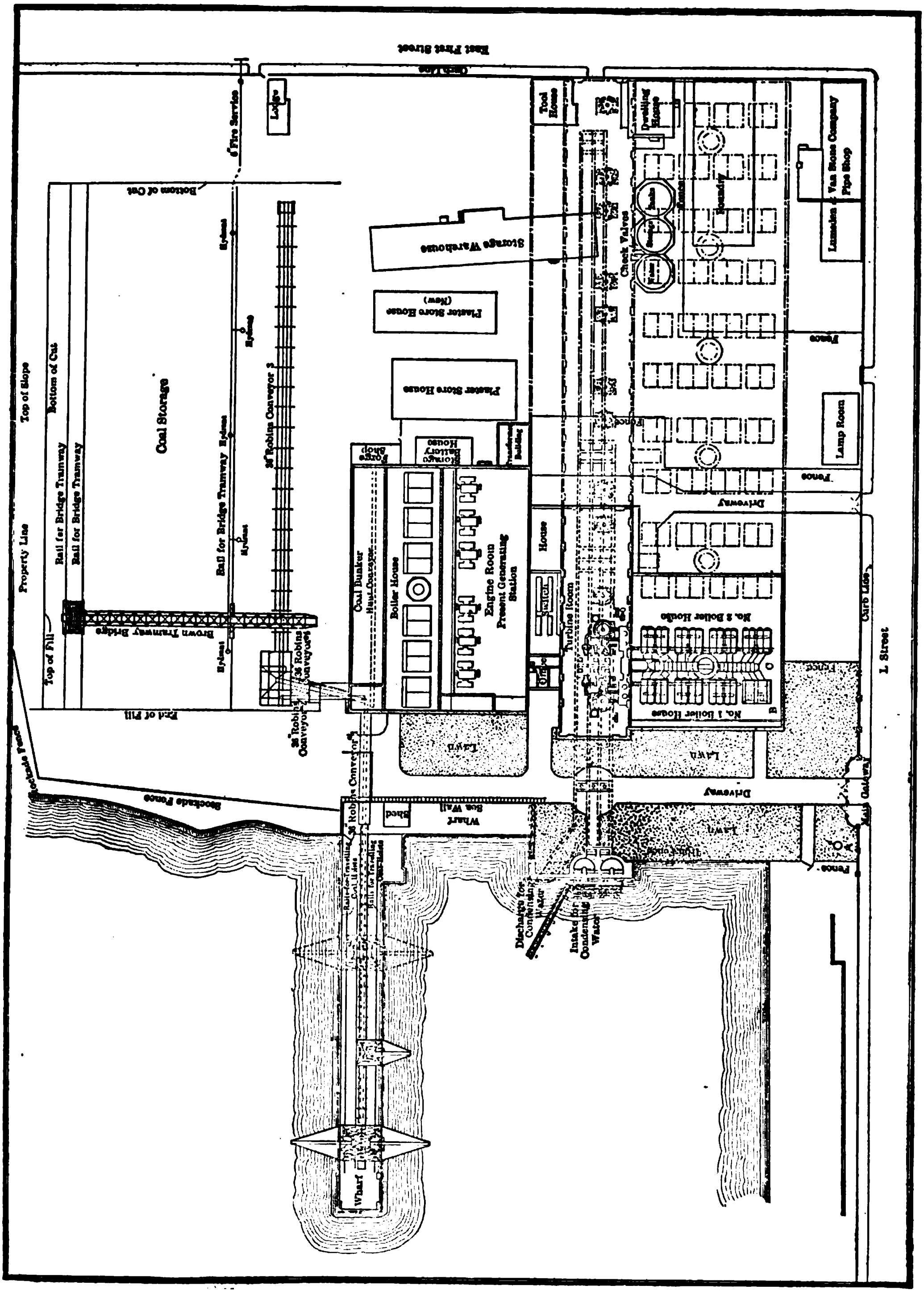


FIG. 3. Plan of Old and New (Turbine) Plants of the Boston Edison Co. (*Power*).

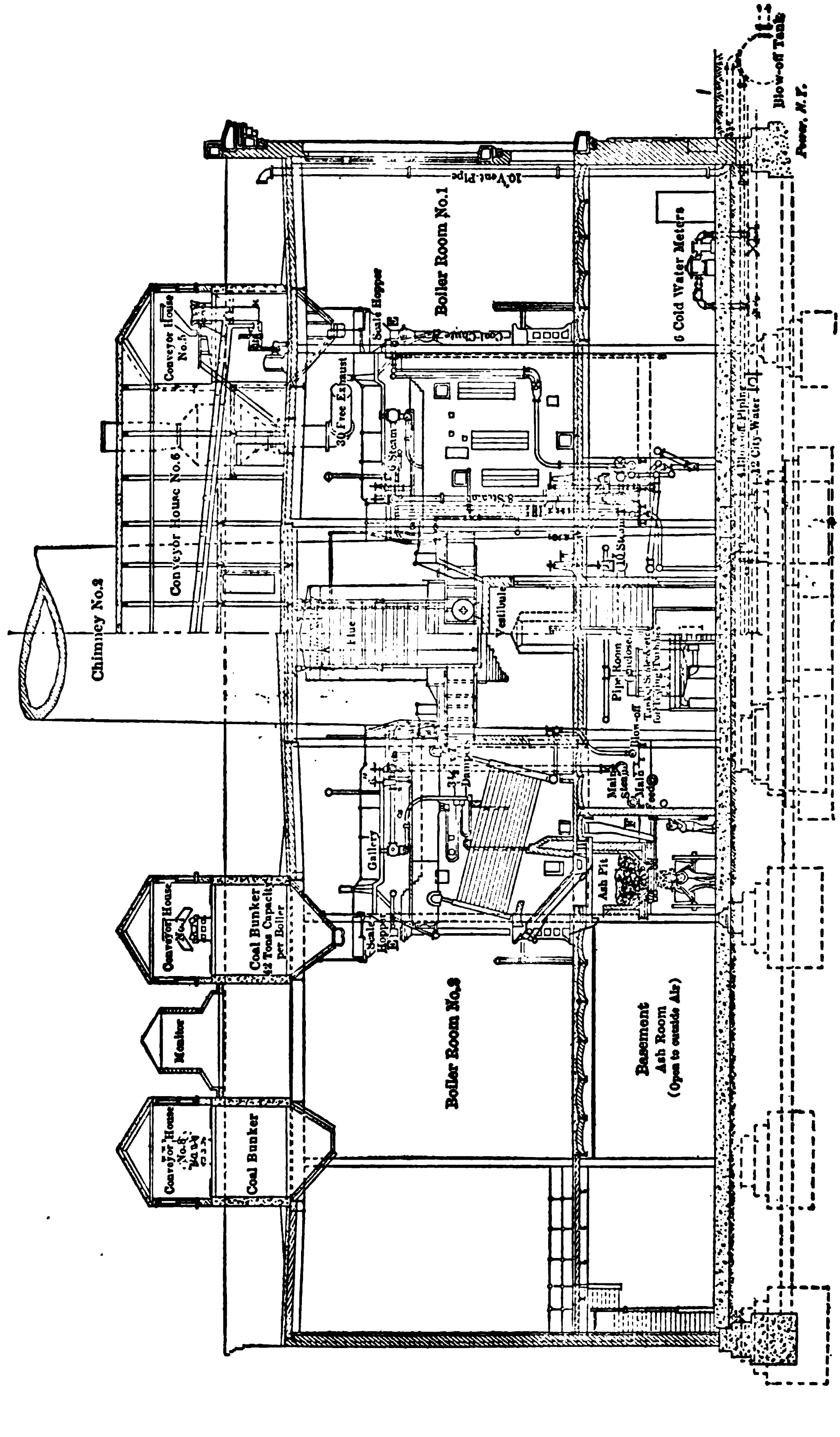


FIG. 4. Transverse Section of Boiler House, L Street Plant, Boston.

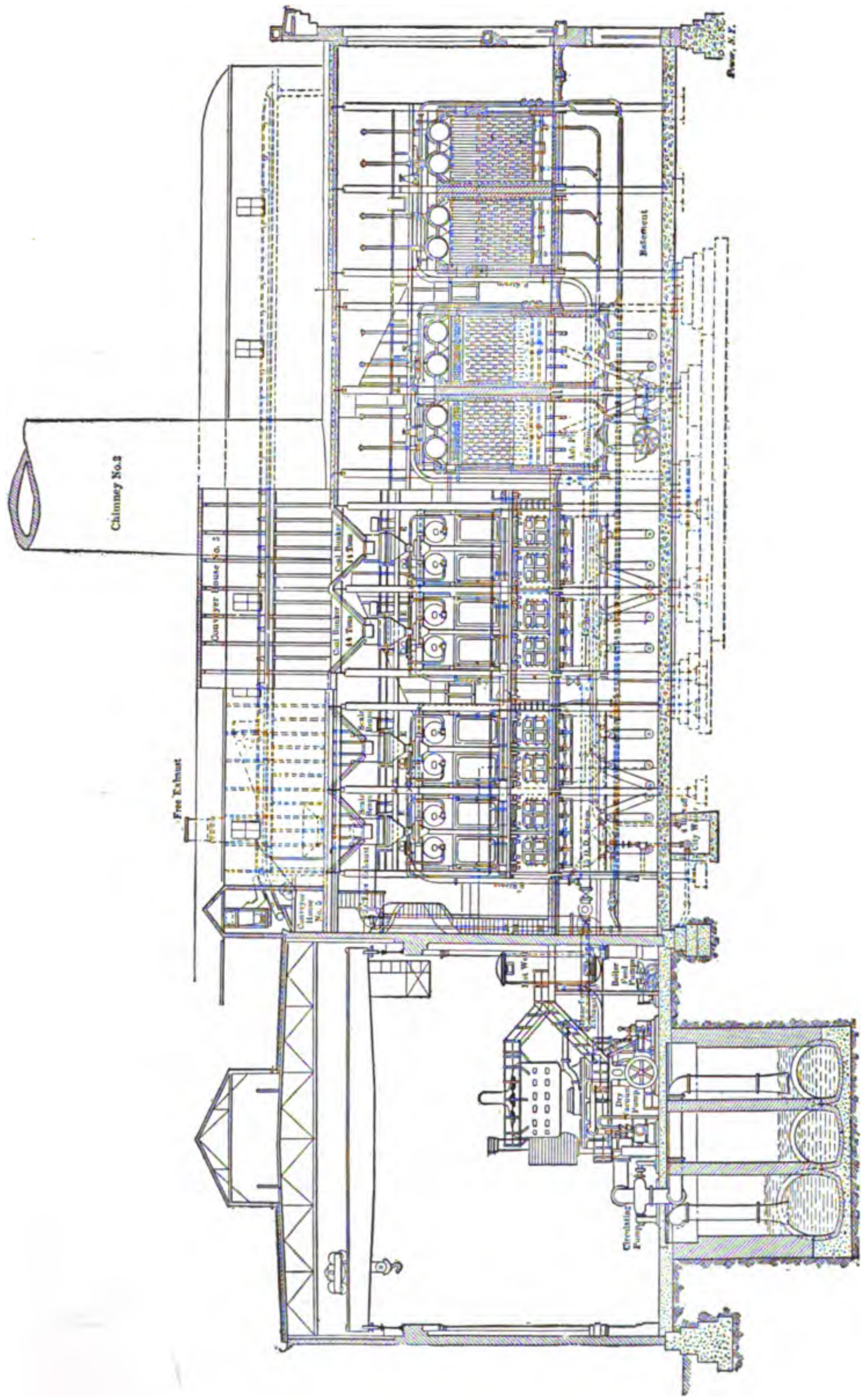


FIG. 5. Longitudinal Section of L Street Plant, Boston.

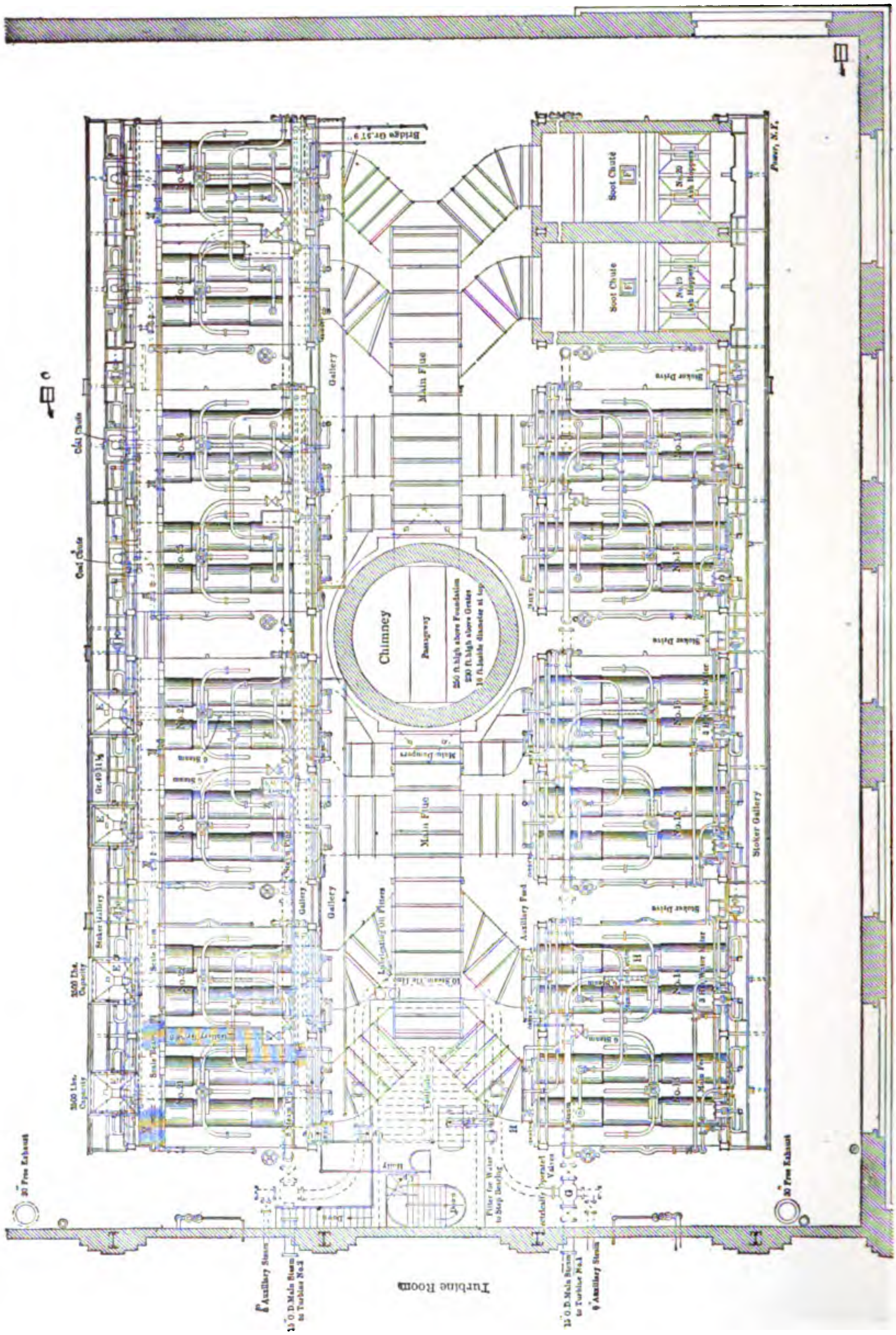


FIG. 6. Plan of Boiler Room, L Street Plant, Boston.

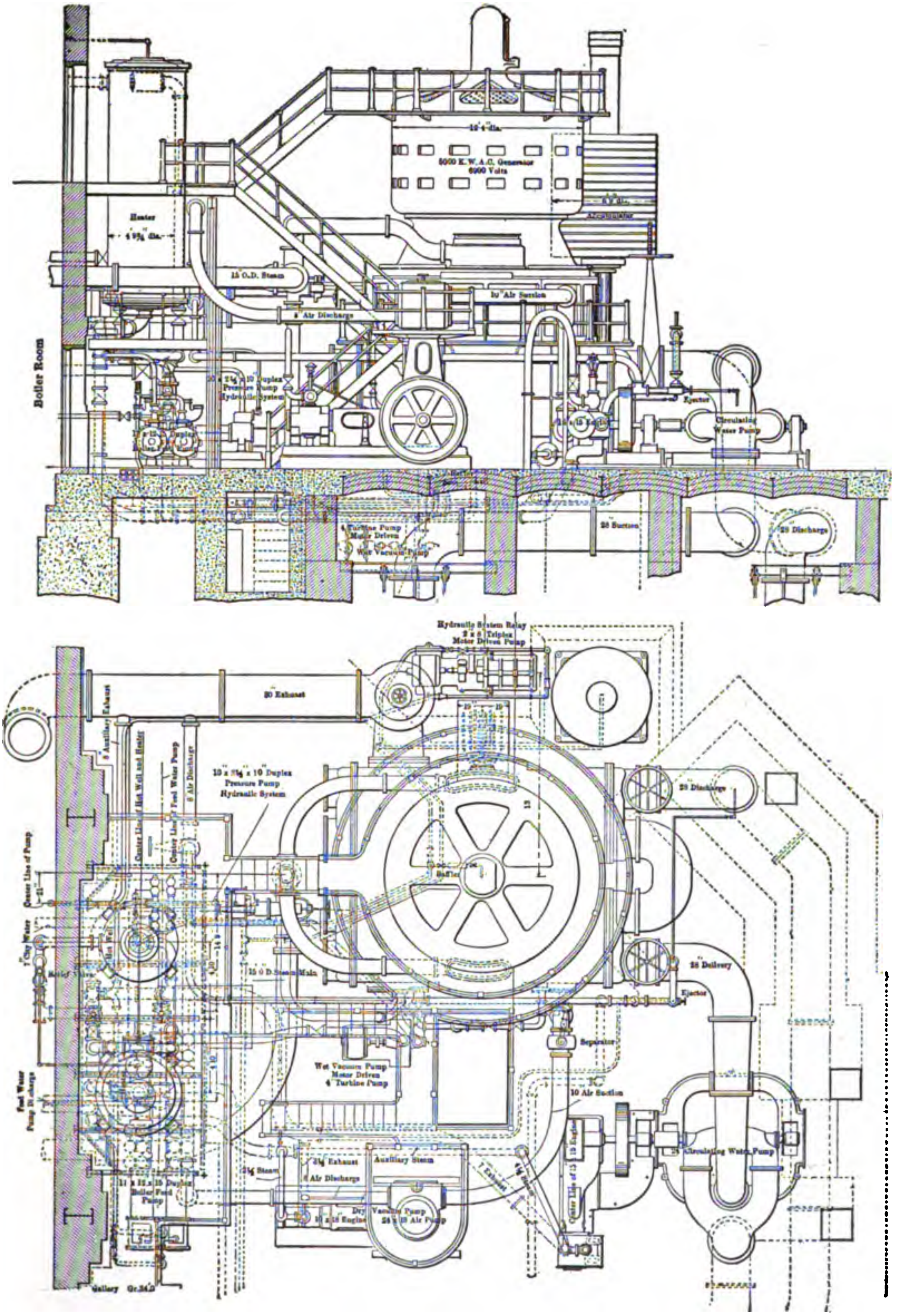


FIG. 7. Plan and Elevation of one 5000-K.W. Turbo-Generator Unit with Auxiliaries, L Street Plant, Boston (*Power*).

59TH STREET PLANT, NEW YORK.

Subject.		Remarks.
Building	693′ 9″ × 200′ 10″	
Boiler room	693′ 9″ × 83′ 0″	Coal bunker, 11,500 tons.
Generating room	693′ 9″ × 117′ 10″	Including switch room, 23 ft. wide.
Boilers (72)	B. & W	One tier.
At present installed	60	One tier.
Size	6,008 sq. ft.	Each.
Pressure	200 lbs.	
Grates, incline type	111.8 sq. ft. (42)	Natural draft.
Grates, hand fired	100 sq. ft. (18)	Forced draft.
Superheater	768 sq. ft. (8)	For turbine.
Superheater	900 sq. ft. (4)	Exclusively.
Steam pipe connection	9″, 18″ O.D. header	Three 10″ equalizing system. Two 15″ to one engine.
Economizer (14)	Sturtevant	Separate tier, above boilers.
Heating surface	107,600 sq. ft.	
Feed pumps		Tanks.
Chimneys (5)	Radial brick	One for 12 boilers.
Height above grate	218′ 0″	Natural draft and forced draft.
Diameter at top	16′ 0″	
Coal Handling System	Movable tower	Steam driven.
Capacity	200 tons hour; 1½ tons bucket	" "
System	Fixed tower	Motor driven.
Capacity	150 tons hour; 1 ton bucket	" "
Conveyor	30″ and 20″ belts	" "
Ash Handling System	Industrial railway	Storage battery locomotive.
Circulating Water.		
Intake	82 sq. ft.	Concrete.
Outlet	70 sq. ft.	Concrete.
Engines (A) (11)	7,500 I.H.P., each	Hor. ver., cross compound.
At present installed (9)	7,500 I.H.P., each	Hor. ver., cross compound.
Pressure	200 lbs.	
Condensers (A)	Barometric jet	Two for one engine.
Circulating pump	Double acting compound	Vertical, 24 suction.
Air pump	Single acting.	Vertical, steam driven.
Generator (A)	5,000 K.W., each	Revolving field.
Volt	11,000	
Phase	3	
Cycle per second	25	
Revolution per minute	75	
Turbo-Generator (B) (3)	1,250 K.W., each	Two-stage Westinghouse-Parsons.
Volt	11,000	
Phase	3	
Cycle per second	60	Lighting exclusively.
Revolutions per minute	1,200	
Condensers, (B)	4,500 sq. ft., each	Each turbine, one apparatus.
Circulating pump	Double acting compound	Vertical.
Air pump	Two-stage	Steam driven.
Hot well pumps	Duplex	" "
Exciters (2)	vertical cross compound	
Capacity,	250 K.W., each	
Revolutions per minute	150	

Subject.		Remarks.
CIRCULATING WATER		
Volt	250	. . . .
Motor generators (3)	250 K.W., each	. . . .
Storage battery	120 cells	3,000 amp. hour at one hour.
AUXILIARIES, electrical.		
Transformers, total	300 K.W.	Six, in two groups.
Volts	250 D.C. and 400 A.C.	. . . .
Storage battery	55 cells	Operates oil switches.
OILING SYSTEM.		
Filtering tanks	2 at 6,500 gallons	Six hundred 3″ × 10″ bags, each.
Elevated supply tanks	2 at 3,500 gallons	25 lbs. pressure.
Pumps (2)	single acting	Steam driven.
CRANES (1)	50 tons	With one 10-ton auxiliary hoist.
" (1)	25 tons	With one 15-ton auxiliary hoist.
Span	72′ 0″	64′ 7″ above generator floor.

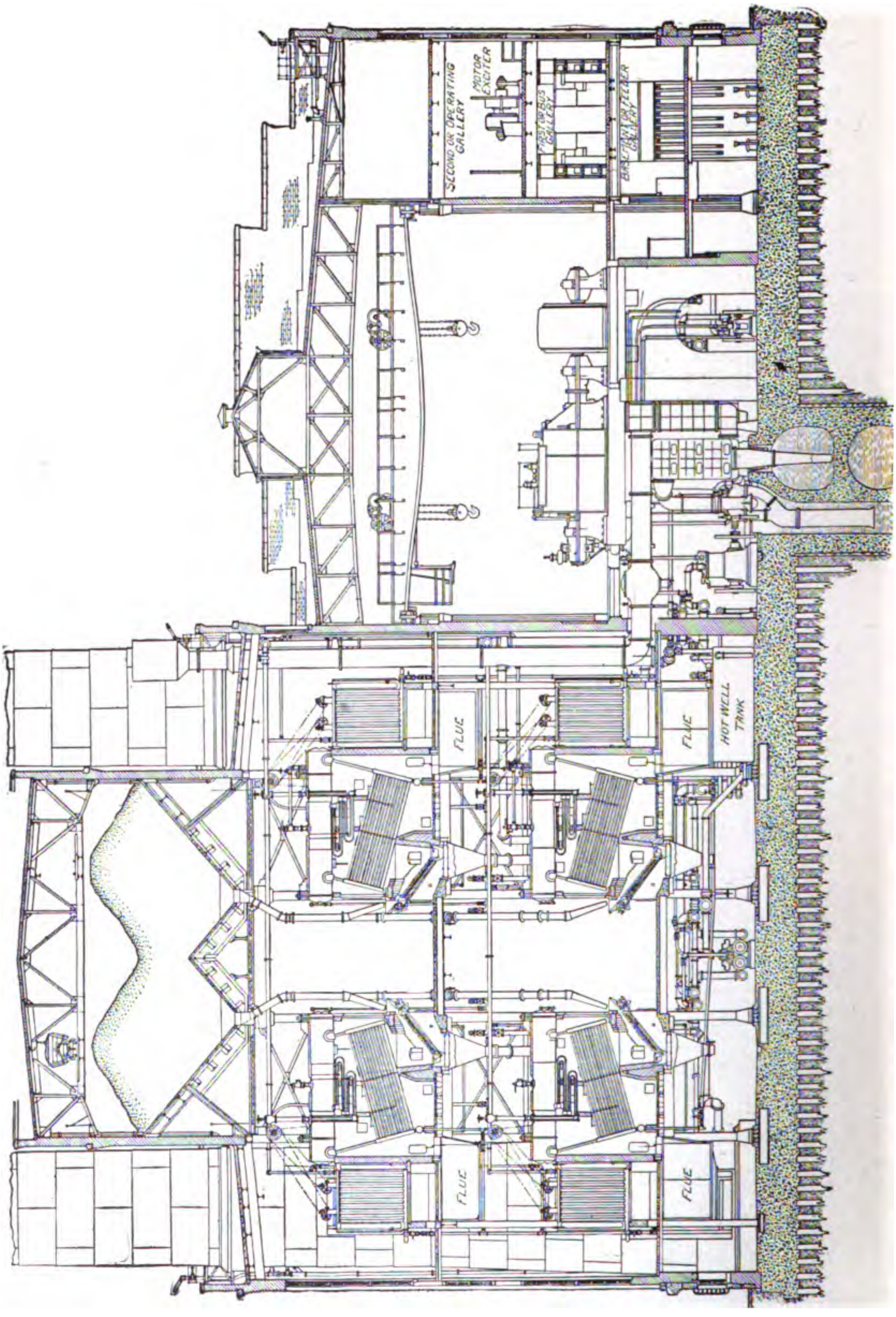


FIG. 1. Cross-Section of the Long Island City Plant of the Pennsylvania Railway Co. (*Street Railway Review*).

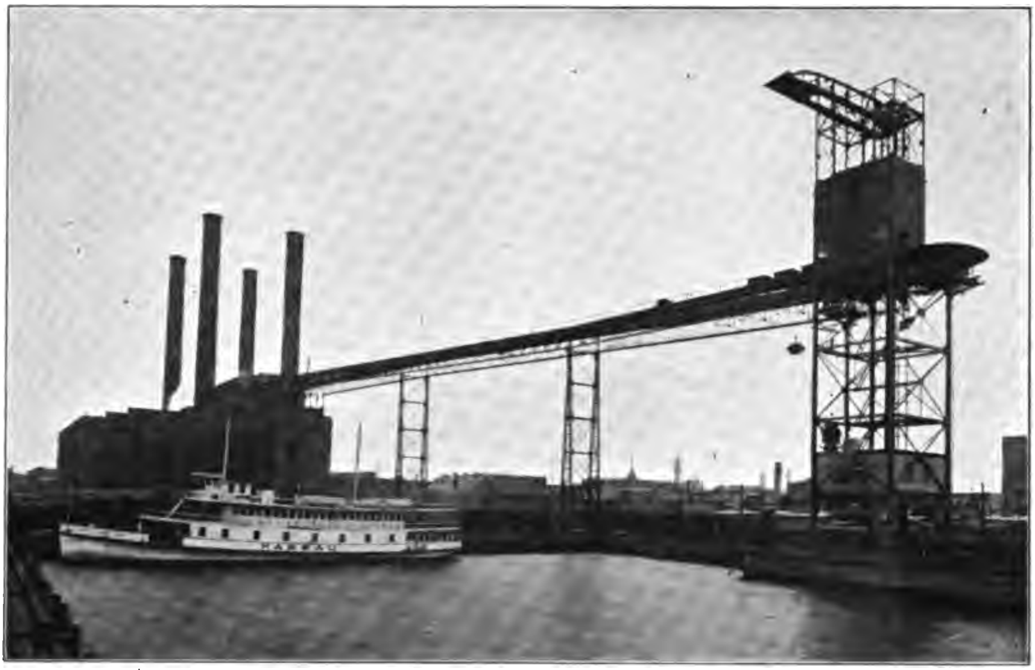


FIG. 2. Long Island City Plant, showing Coal Tower in Operation.

FIG. 3. Coal Conveyor, viewed from Tower, Long Island City Plant.

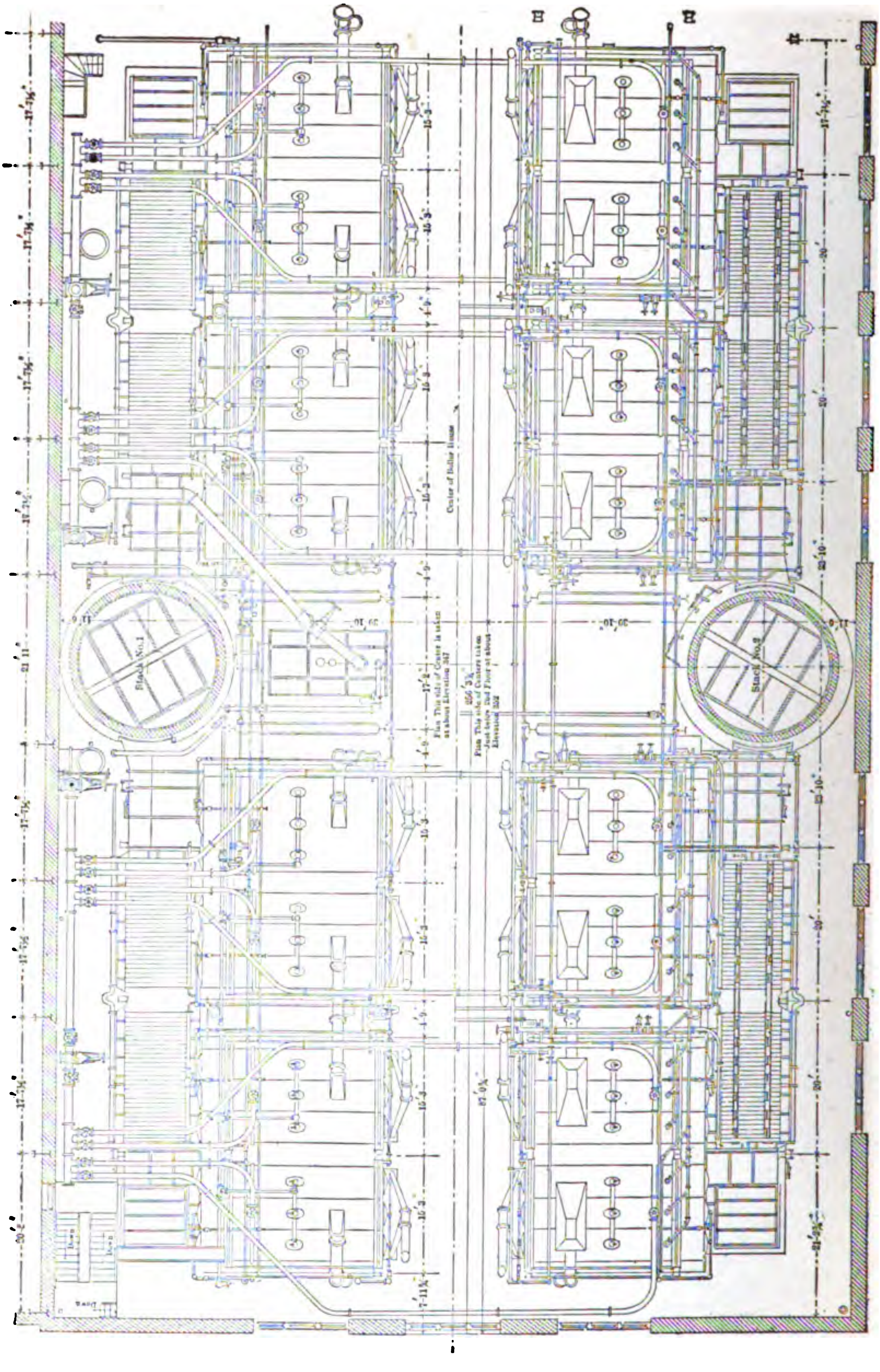


FIG. 4. Plan of First Floor of Boiler House, Long Island City Plant (*Power*).

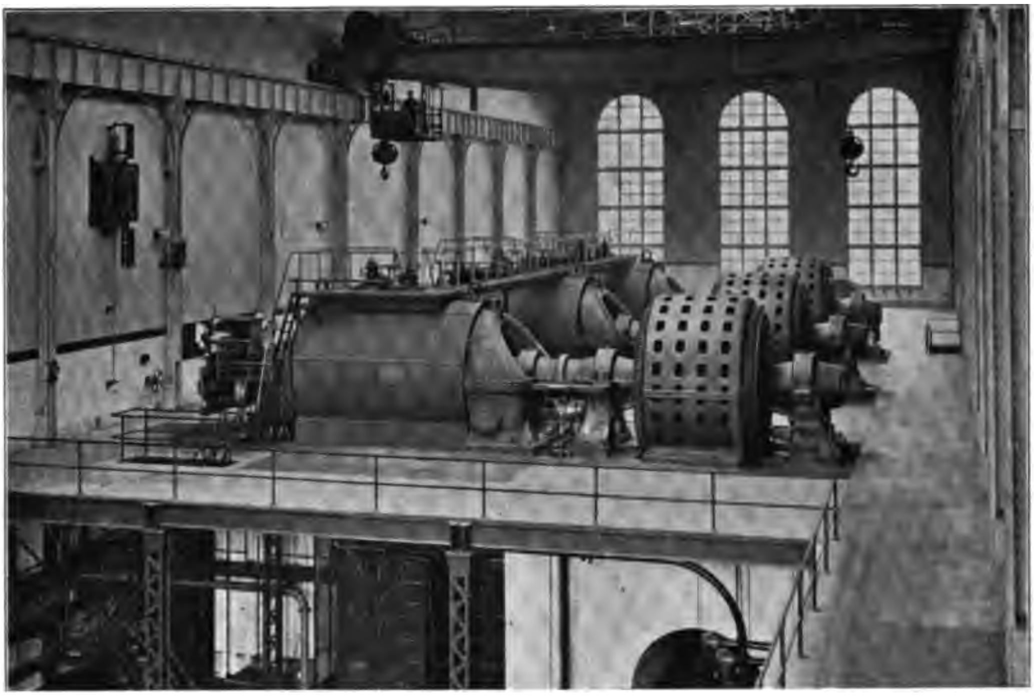


FIG. 5. Interior of Generating Room, Long Island City Plant, 5000-K.W. Parsons Turbines.

FIG. 6. Oil Switch and Bus-Bar Compartments, Long Island City Plant.

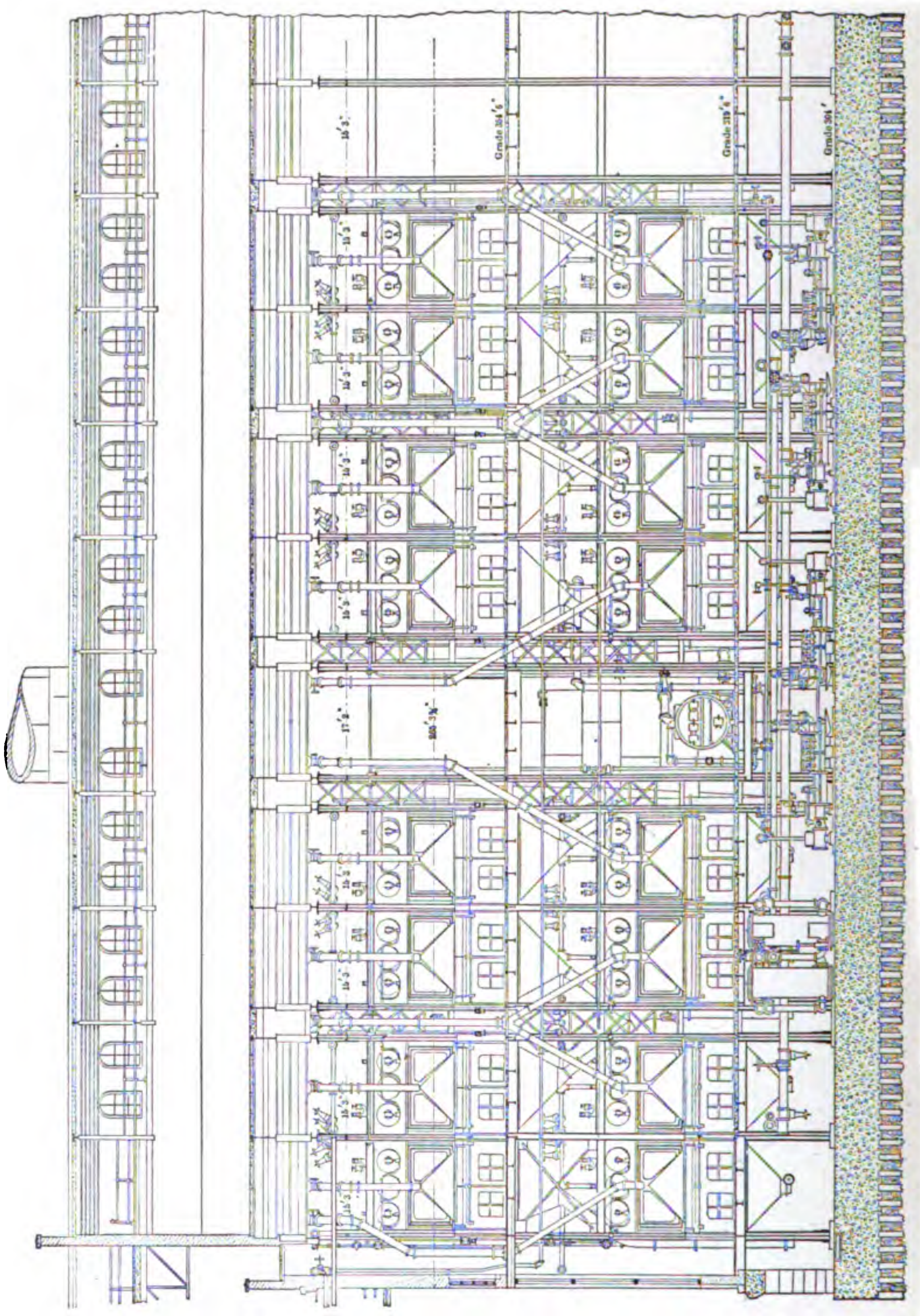


FIG. 7. Longitudinal Section of Boiler House, Long Island City Plant (*Power*).

FIG. 8. Electrical Operating Gallery, Long Island City Plant.

FIG. 9. Bus Gallery, showing Main Generator and Rheostats and Auxiliary Wiring Long Island City Plant.

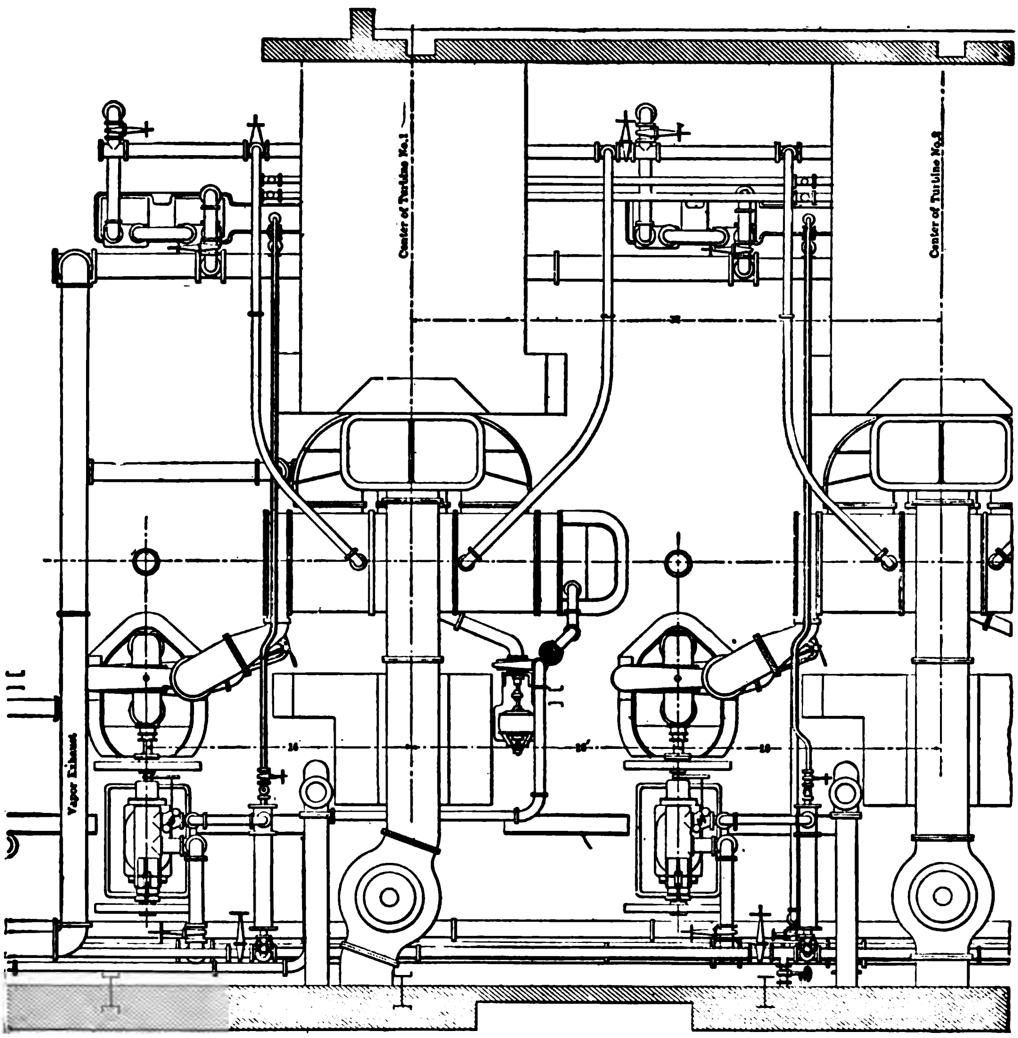


Fig. 10. Turbine Room, Basement, Long Island City Plant.
(Showing Condensers and Pumps.)

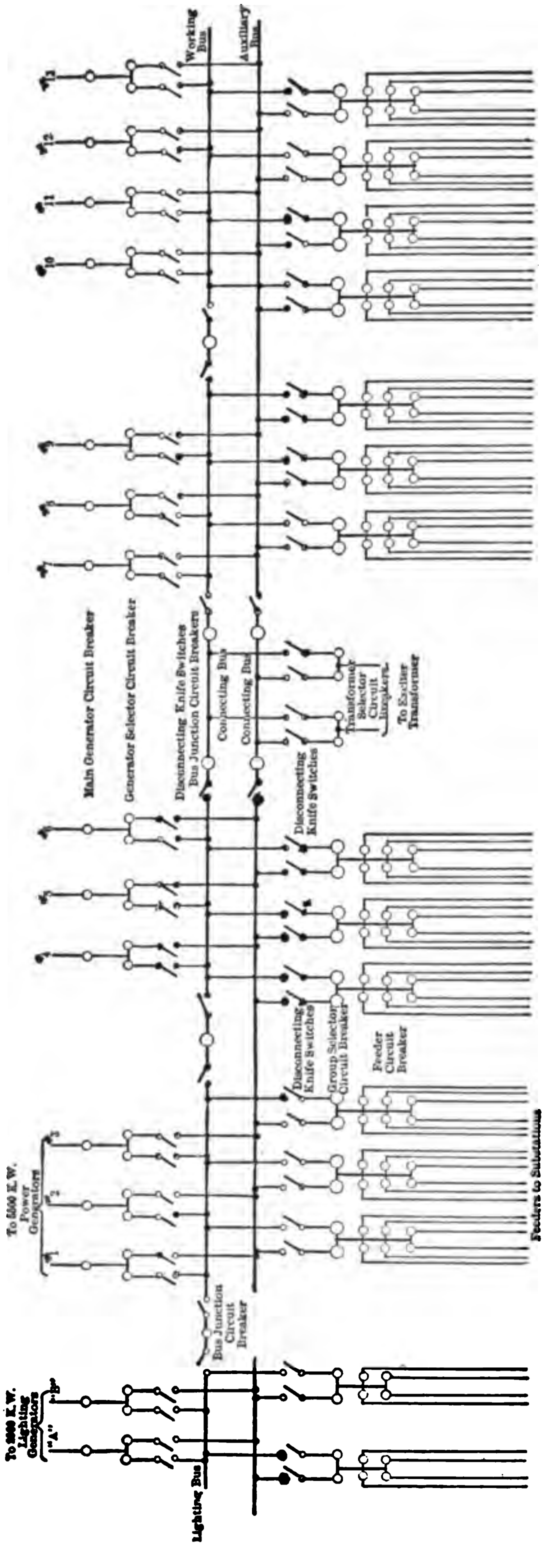


FIG. 11. High-Tension Wiring Diagram, Long Island City Plant (*Power*).

Subject.		Remarks.
Buildings	143′ 6″ × 175′ 0″	
Boiler room	143′ 6″ × 100′ 0″	Coal bunkers, 15,000 tons.
Generating room	143′ 6″ × 75′ 0″	Including switch room, 14′ 0″ wide
Oil-Cooling Building	50 ft. high	Three storage.
Barge Basin	220′ 0″ × 80′ 0″	Accommodates 6 barges.
Boilers, accommodate (80)	B. & W	Two tiers.
At present installed	64	" "
Capacity, each	5,212 sq. ft.	
Pressure	175 lbs.	
Stokers, chain-grate	83 sq. ft.	Motor driven.
Superheater	672 sq. ft.	
Steam pipe connection	6″	14″ header.
Economizers (20)	Green	Two tiers, in rear of boilers.
Heating surface, total	105,000 sq. ft.	Motor cleaned.
Heating surface, per boiler	1,640 sq. ft.	
Chimneys	4	Radial brick.
Height above lower grates	253′ 0″	Natural draft.
Diameter at top	19′ 0″	
Coal Handling system	2 Gantrie cranes	Motor driven.
Conveyor	30″ belt	" "
" (2)	buckets	" "
" (2)	20″ belts	" "
Ash Handling system	Industrial railway	Storage battery locomotive.
Circulating Water.		
Intake	5′ 6″ diameter	C. I. and W. I.
Outlet	5′ 6″ diameter	" " "
Feed Water	8½″ artesian well	
Pumps (8)	vertical plunger	Steam driven.
Capacity, each	18,000 gallons	
Turbines, accommodate (10)	5,000 K.W. each	British Westinghouse-Parsons.
" " (1)	2,700 K.W. each	" " "
" at present installed (8)	5,000 K.W. each	" " "
Pressure	165 lb.	
Temperature, superheat	100° Fahr.	
Condensers, each	15,000 sq. ft.	Vertical, surface.
Vacuum	27″	90 per cent.
Circulating pump	20″	Motor driven.
Hot well pump	4″	" "
Vacuum pump	Dry air	" "
Generator	5,000 K.W.	"Open" type.
Volt	11,000	
Phase	3	
Cycle per second	33⅓	
Revolution per minute	1,000	
Exciters (4)	vertical two-cylinder compound	
Capacity, each	150 K.W.	25 per cent overload capacity.
Revolutions per minute	375	
Volt	125	
Auxiliaries, electrical.		
Motor generator (1)	125 K.W.	Charging battery, light, etc.
Volt	125	
Storage battery		Operate oil switches.
Transformers, total	150 K.W., 11,000 — 220 volts	Three groups.
Oiling, system.		
Pumps (3)	centrifugal	Motor driven.
Oil cooler (3)	3,330 sq. ft. each	Oil is cooled then filtered.
Total capacity per min.	350 gallons	

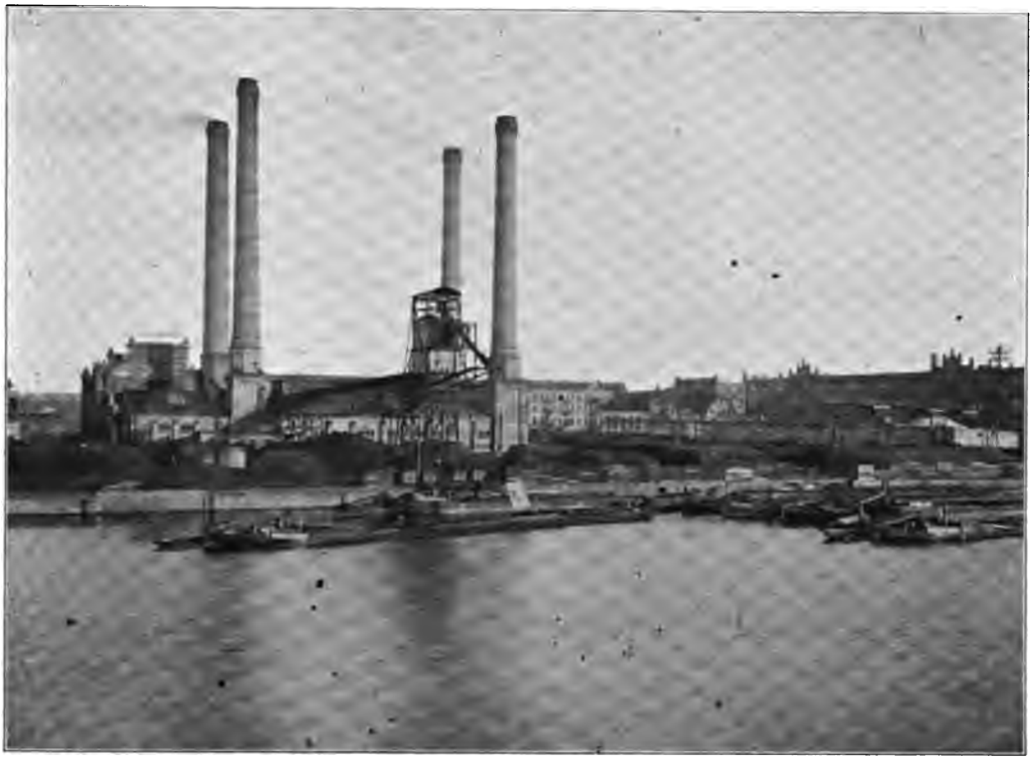


FIG. 1. Light and Power Plant, "Oberspree," Berlin.

FIG. 2. Interior of Engine Room, "Oberspree," Berlin.

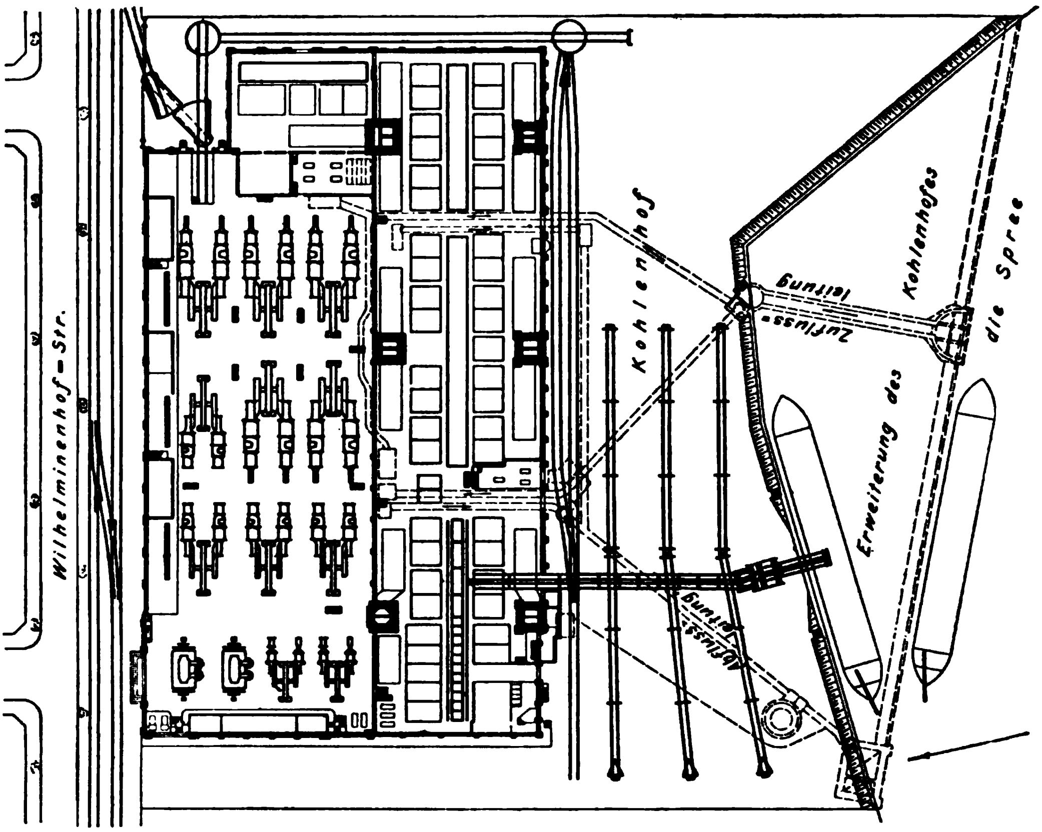


FIG. 3. Plan of "Oberspree" Plant, Berlin. Coal Handling System and Storage at Right Hand (*Zeitschrift des Vereines deutscher Ingenieure*).

FIG. 4. Light and Power Plant, "Moabit" Plant, Berlin.

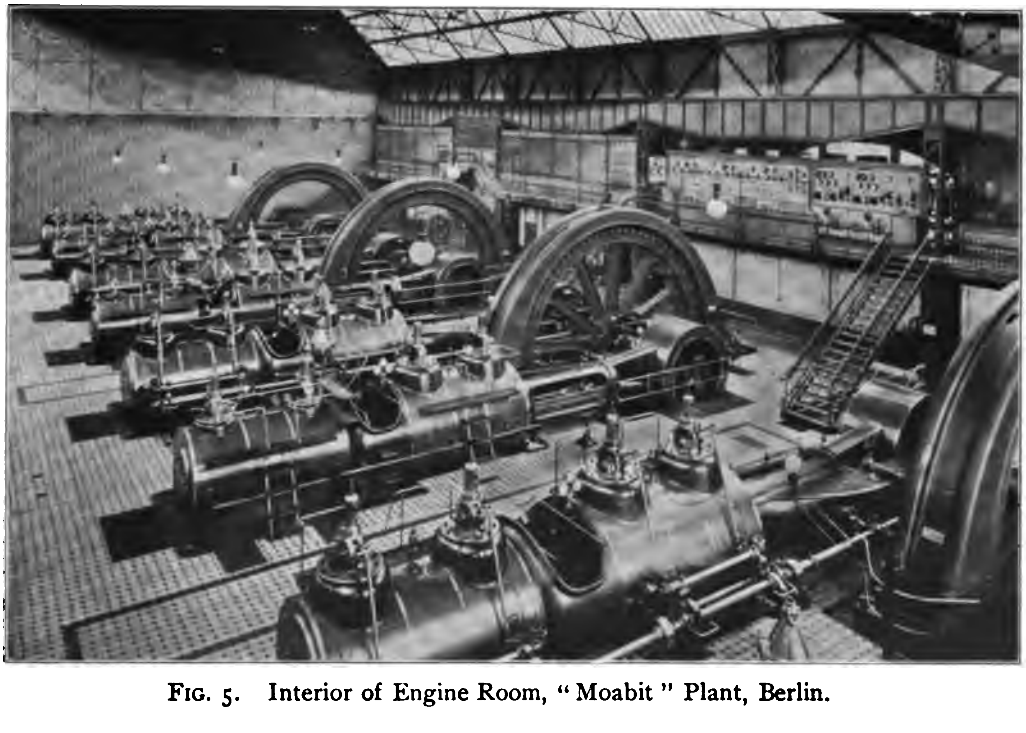


FIG. 5. Interior of Engine Room, "Moabit" Plant, Berlin.

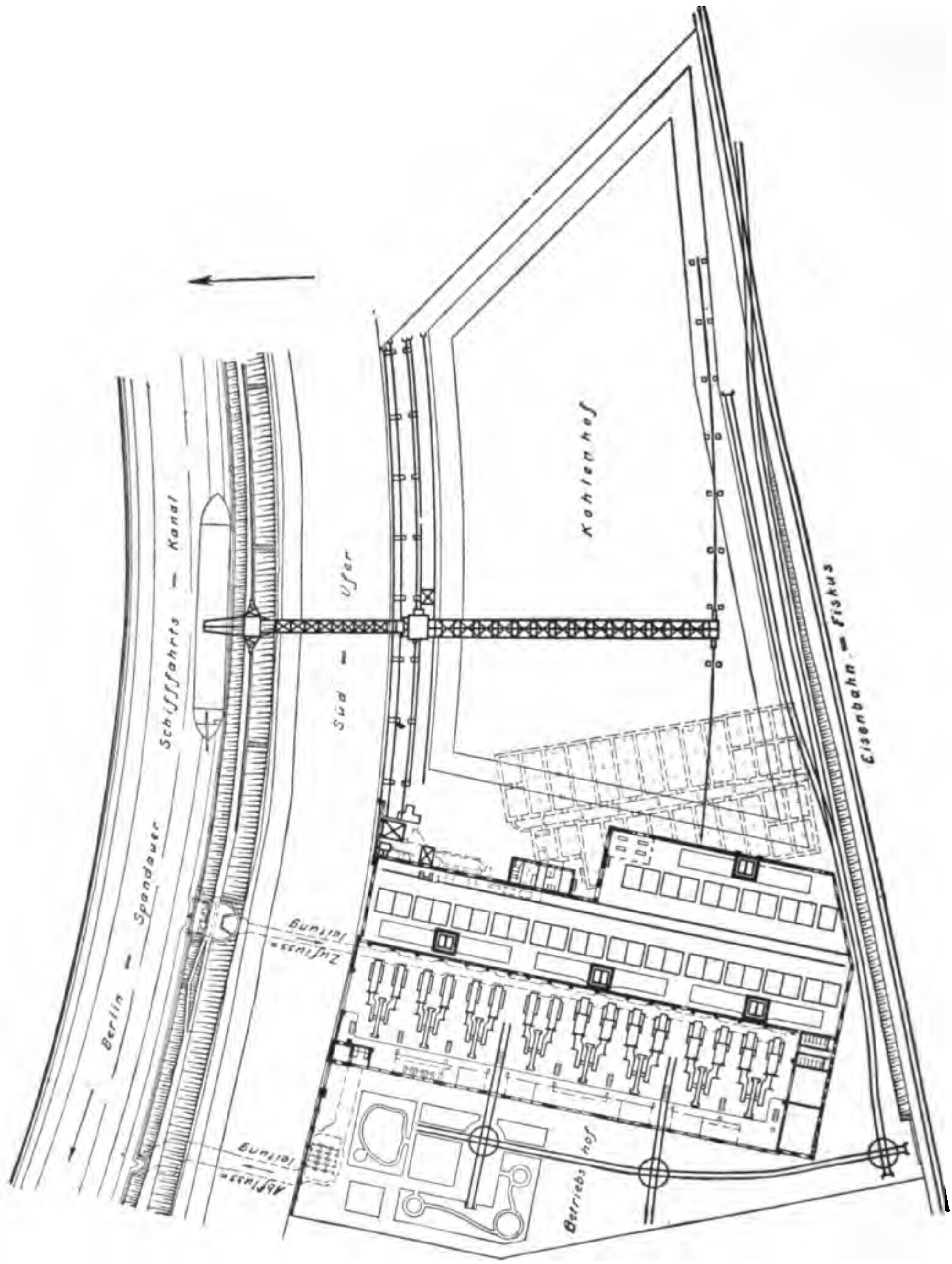


FIG. 6. Plan of "Moabit" Plant, Berlin (*Zeitschrift des Vereines deutscher Ingenieure*).

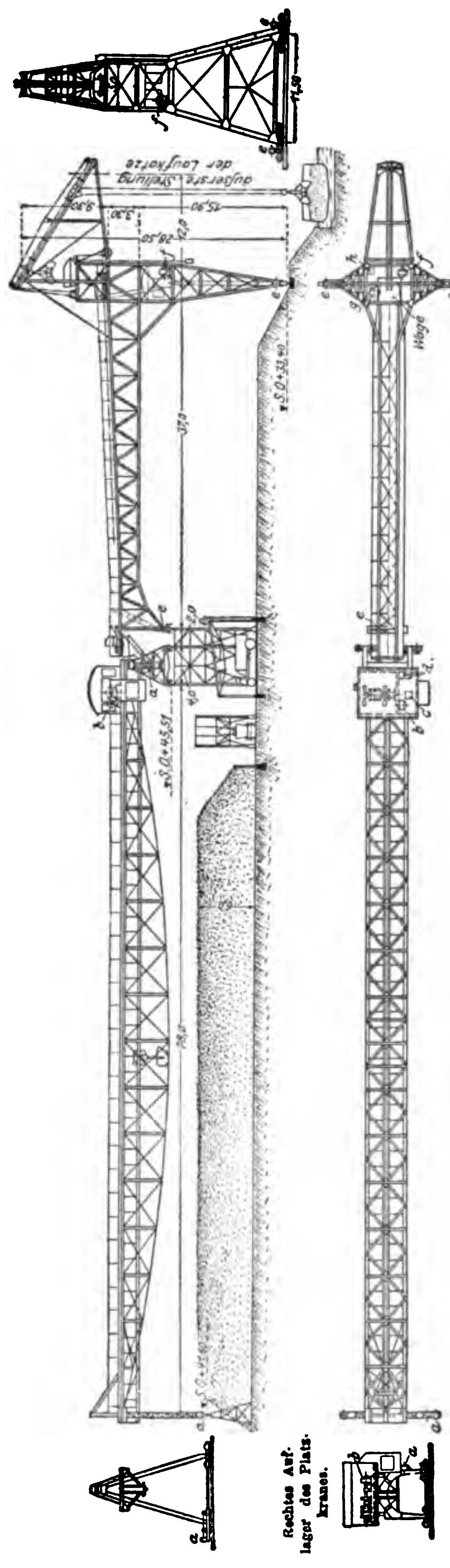


FIG. 7. Coal Handling System of "Moabit" Plant, Berlin (*Zeitschrift des Vereines deutscher Ingenieure*).

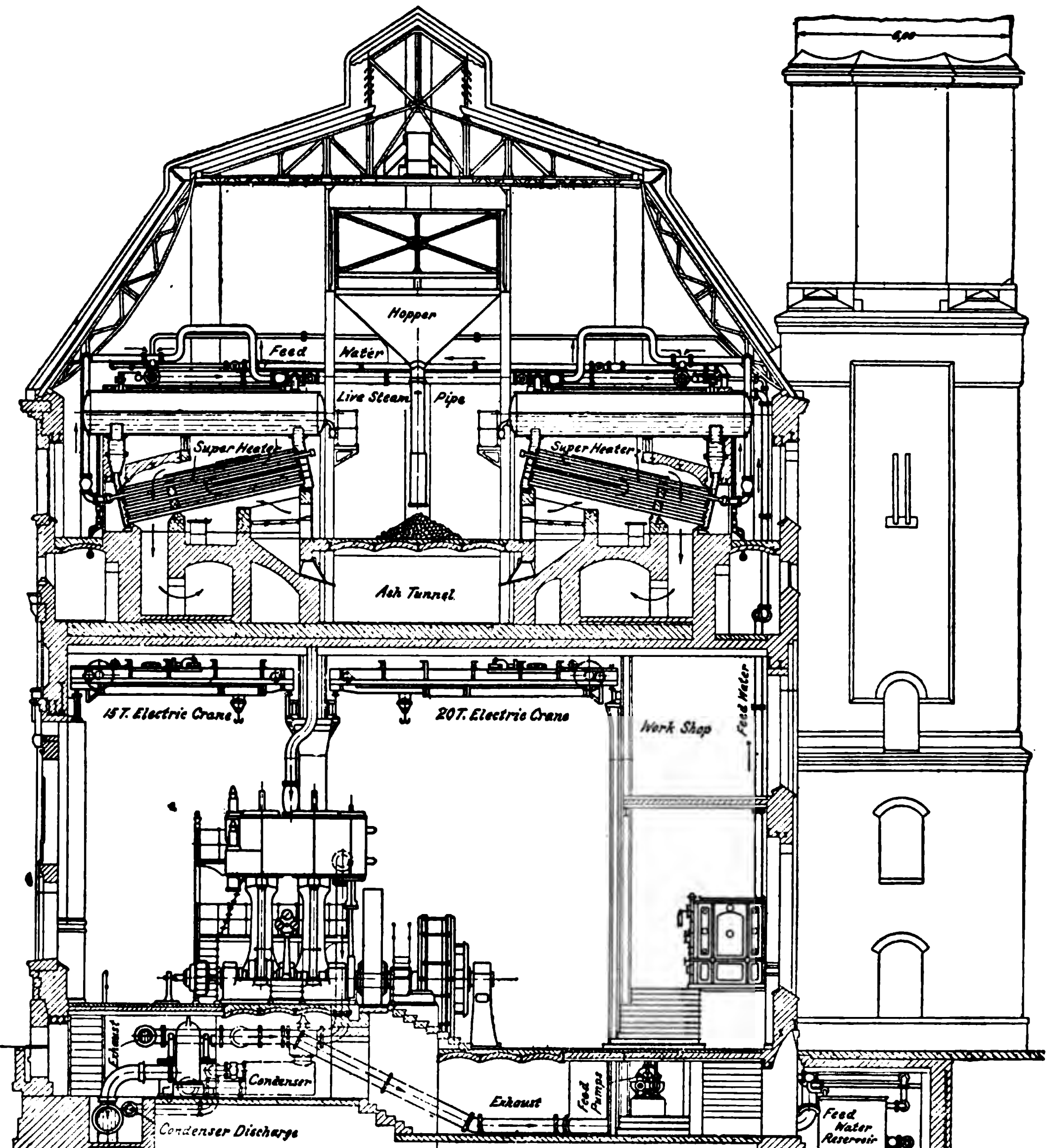


FIG. 8. Trebbiner St. Plant of the Elevated R.R., Berlin (*Power*).

Subject.		Remarks.
Buildings.		
Boiler rooms, each	140′ × 140′	3 separate buildings.
Feed water rooms, each	140′ × 19′ 6″	Pumps, purifier, tanks, etc.
Coal and ash buildings, each	140′ × 140′	3 buildings.
Generating room	656′ × 65′ 6″	1 building.
Switching room	620′ × 25′	1 building.
Boilers, number	60	B. & W. marine type.
At present installed	20	. . . .
Under construction	20	. . . .
Size	4,500 sq. ft.	Each.
Pressure	175 lbs.	. . . .
Superheat	640 sq. ft.	. . . .
Grate	70 sq. ft.	Chain grate.
Grate operation	10 H.P. for 5 grates	Motor driven.
Pipe connection	5″ boiler, 12″ header	Inter-connected, 8″ pipe.
Economizers, each	1,720 sq. ft.	One per boiler.
Scraper	15 H.P. for 5 economizers	Motor driven.
Water Purifiers, each	185 gal. (U.S.), 145 gal. (Brit.)	One for 10 boilers, for "make up" water only.
Feed Pumps	4 per 20 boilers	. . . .
" " (3)	triplex acting plunger	80 H.P. motor.
" " (1)	centrifugal	100 H.P. motor.
Chimneys (12)	radial brick	One for 5 boilers.
Height above grate	165′ 0″	. . . .
Diameter at top	10′ 0″	. . . .
Coal Conveyor System	Two 40–50 ton locomotive cranes	Motor driven.
Coal-building capacity	16,000 tons	Per building.
Bunkers	80 tons	Per 2 boilers.
Conveyor	Bucket	For coal and ashes.
Circulating Water	2 intake tunnels	Concrete.
" "	2 outlet tunnels	"
Turbines	12	Brown-Boveri-Parsons.
At present installed	4	. . . .
Under construction	4	. . . .
Capacity	5,000 K.W.	Each.
Steam pressure	175 lb.	. . . .
Steam temperature	570 ° Fahr.	Total.
Revolutions per minute	750	. . . .
Condenser Plant	Surface	. . . .
Circulating pump, each	150 H.P., vertical motor	Double section, centrifugal.
Air pump (wet)	50 H.P., horizontal	Three-cylinder, single acting.
Generator	5,000 K.W.	Brown-Boveri.
Types	3-phase, 25-cycle, 10,250 volts	Fan cooled.
"	2-phase, 42-cycle, 12,500 volts	" "
Exciters.		
Turbo-generator (1)	300 K.W., 220 volts	For exciter, motors, etc.
Condenser	Surface	. . . .
Circulating pump	16.5 H.P. motor	. . . .
Air pump (wet)	9 H.P. motor	. . . .
Motor generators (2)	375 K.W. each	3-phase, 25-cycle, 10,250 volts.
Volt	220	. . . .
Auxiliaries, electrical.		
Booster	110 H.P., 220 volt	. . . .
Storage battery	126 cells	1,300 amp. hour per hour.
Polymorphic set	Two 750-K.W. alternators (1,500 K.W.) and two generators	12,500 volts and 10,250 volts. D.C. 550 volts.

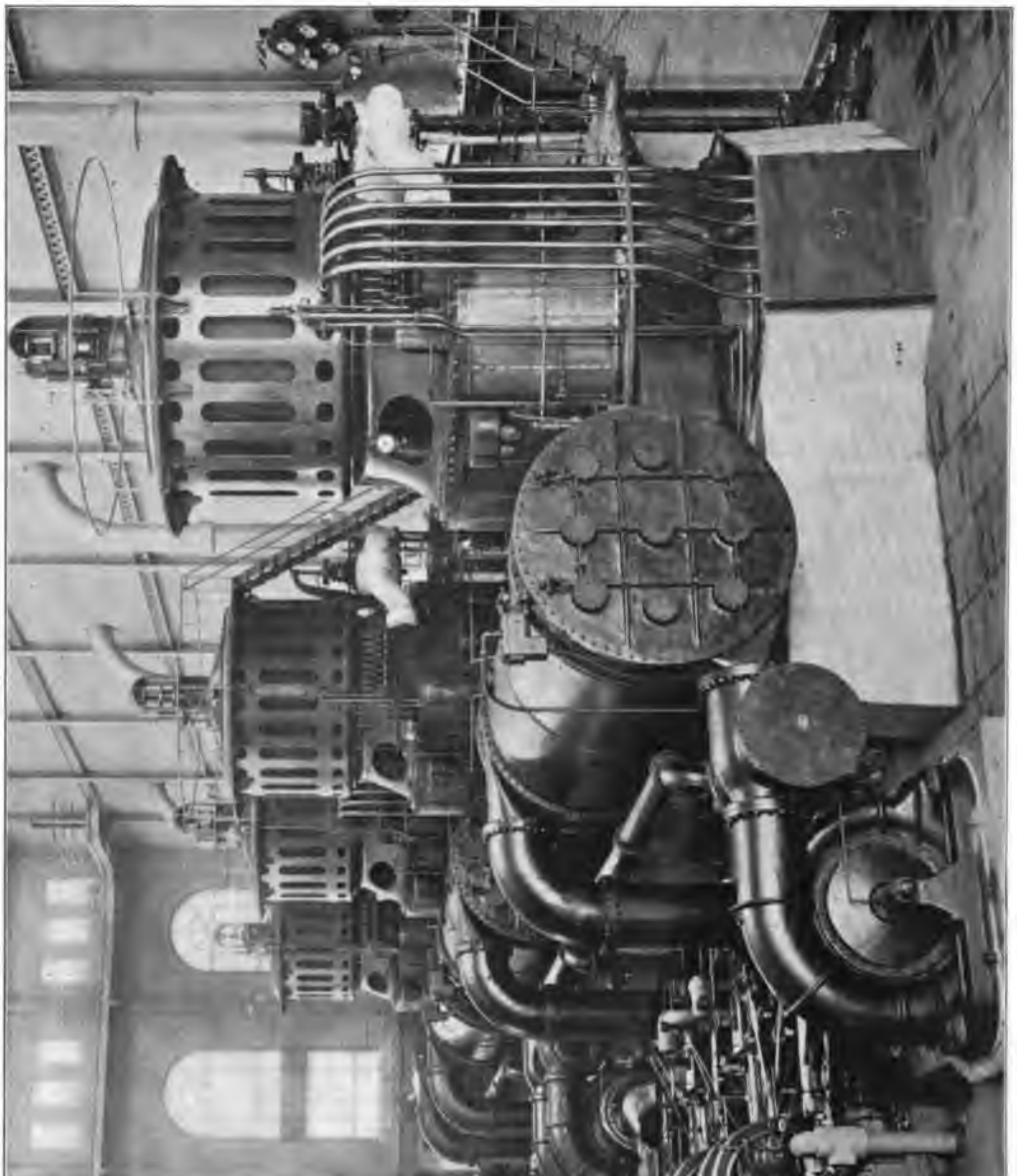


FIG. 1. Generating Room, Port Morris Plant, New York.

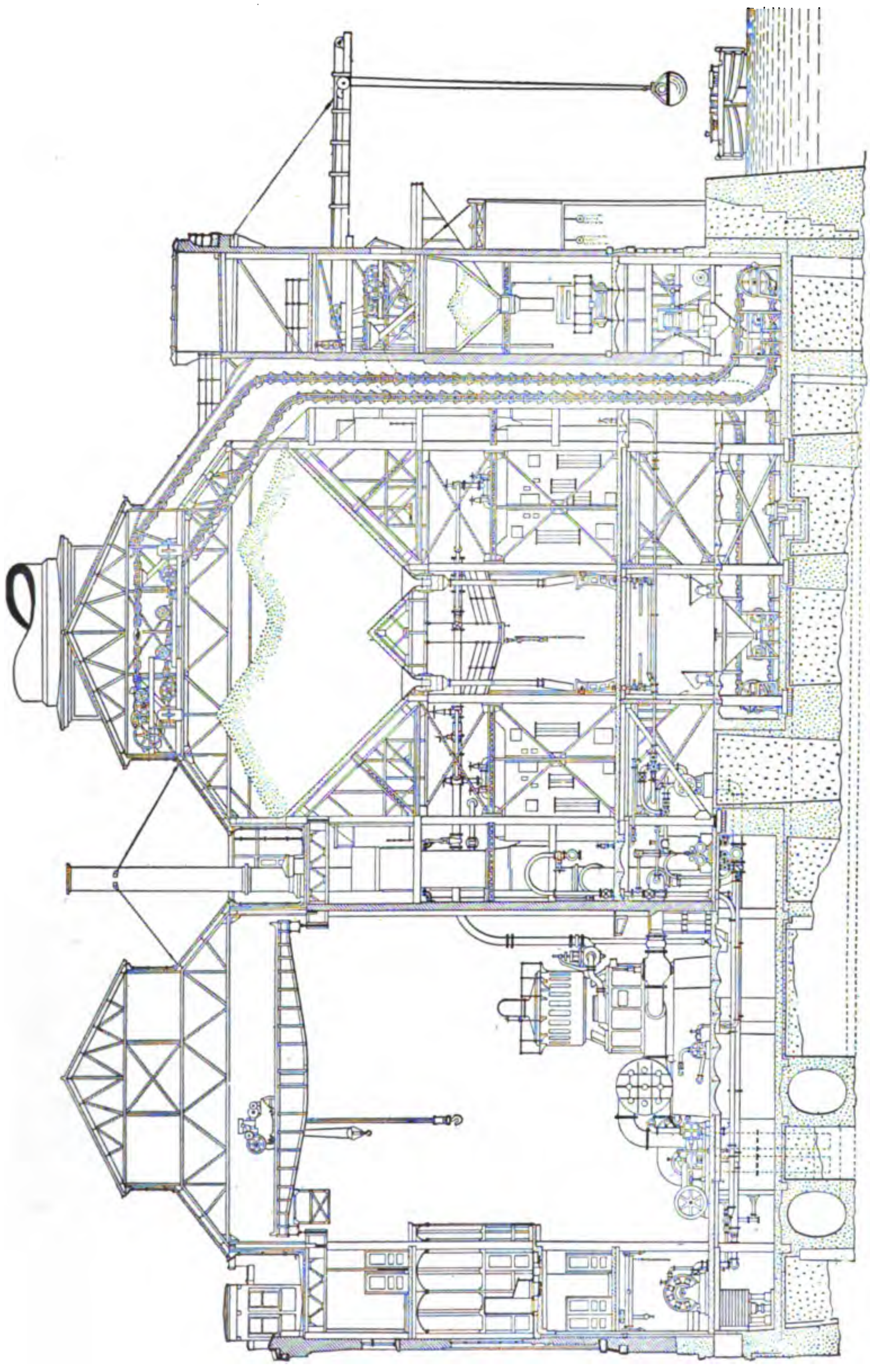


FIG. 2. Cross-Section, Coal and Ash Handling System, Port Morris Plant, New York (*The Engineer*).

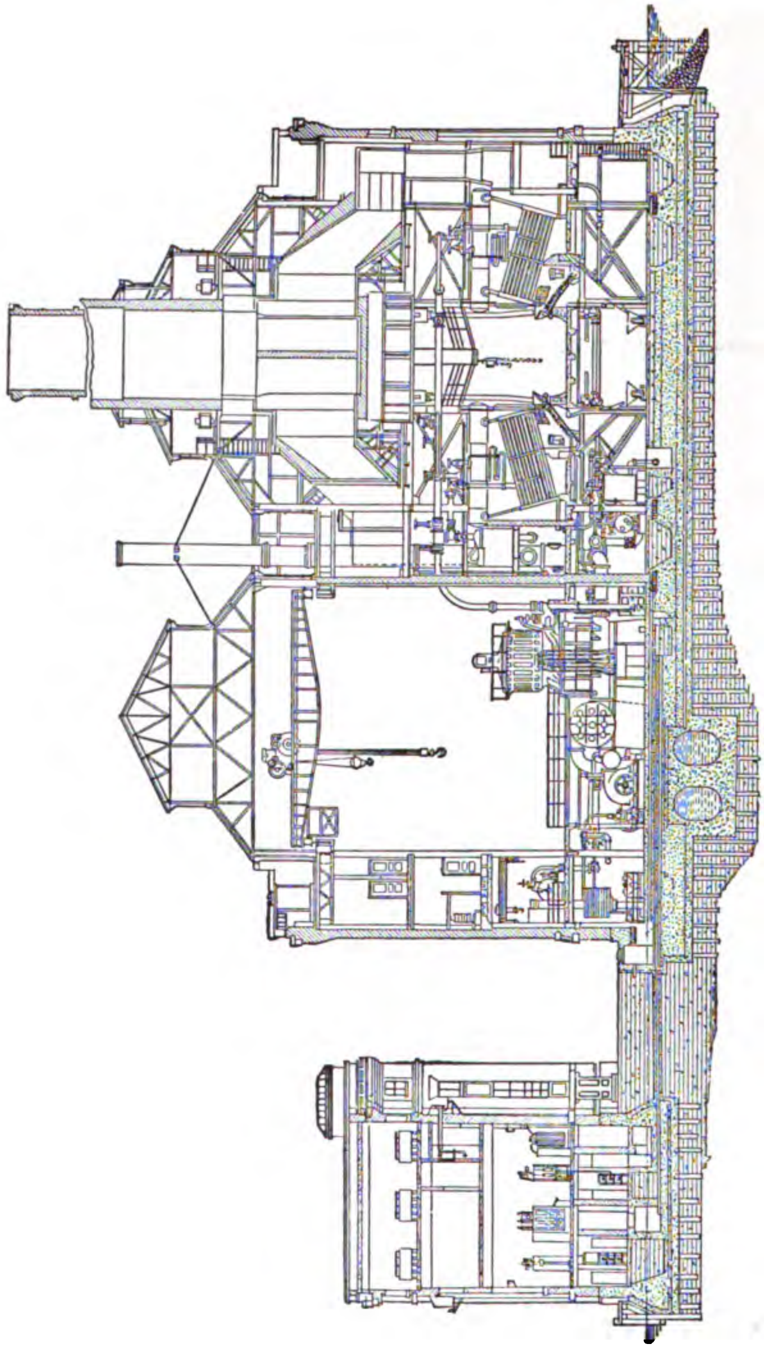


Fig. 3. Cross-Section of "Yonkers" Plant, New York, Switch House at left hand (*Power*).

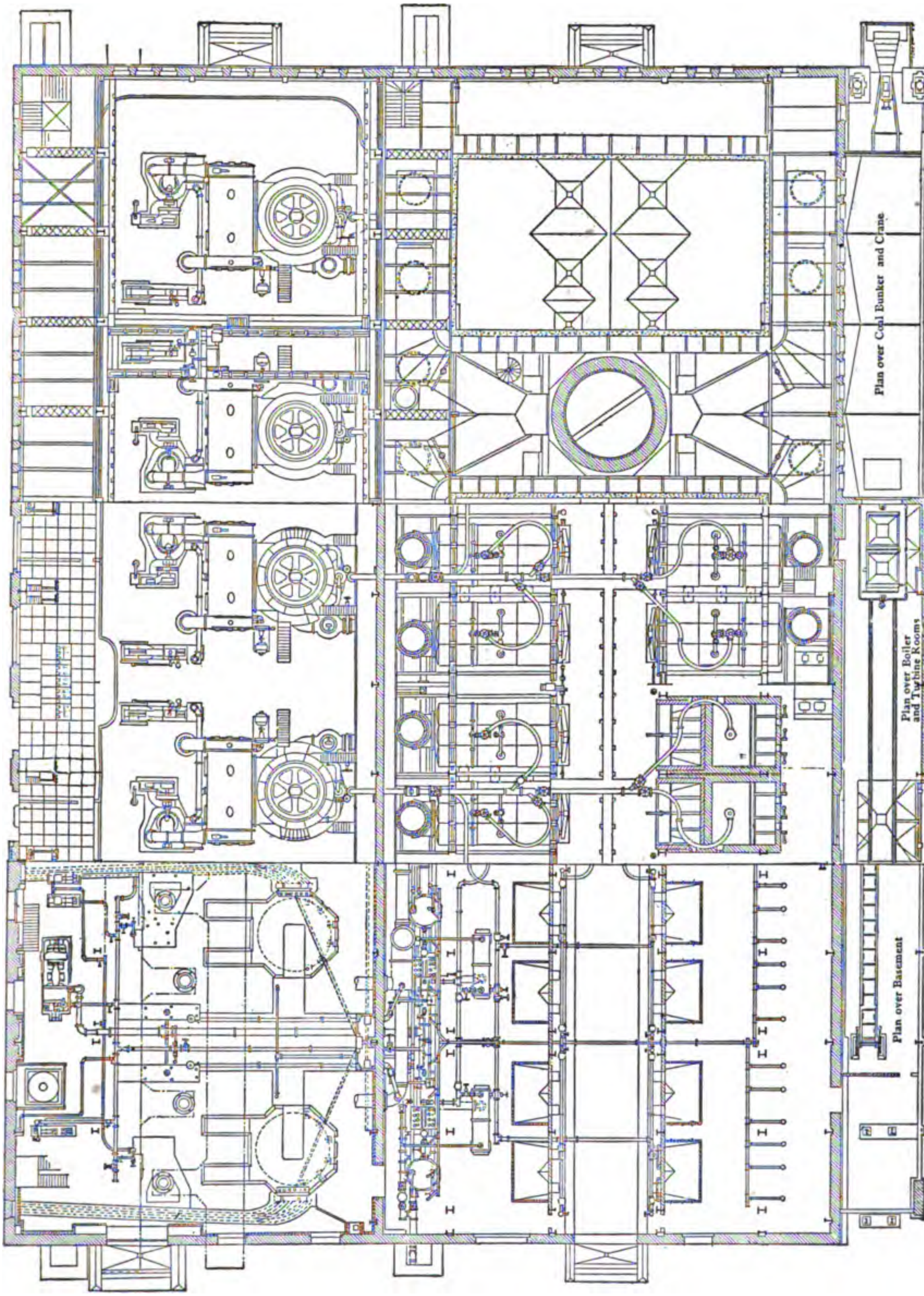


FIG. 4. Plan of Port Morris Plant of the New York Central and H.R. R.R. (*Power*).

FIG. 5. Interior of Boiler Room, "Port Morris" Plant, New York.

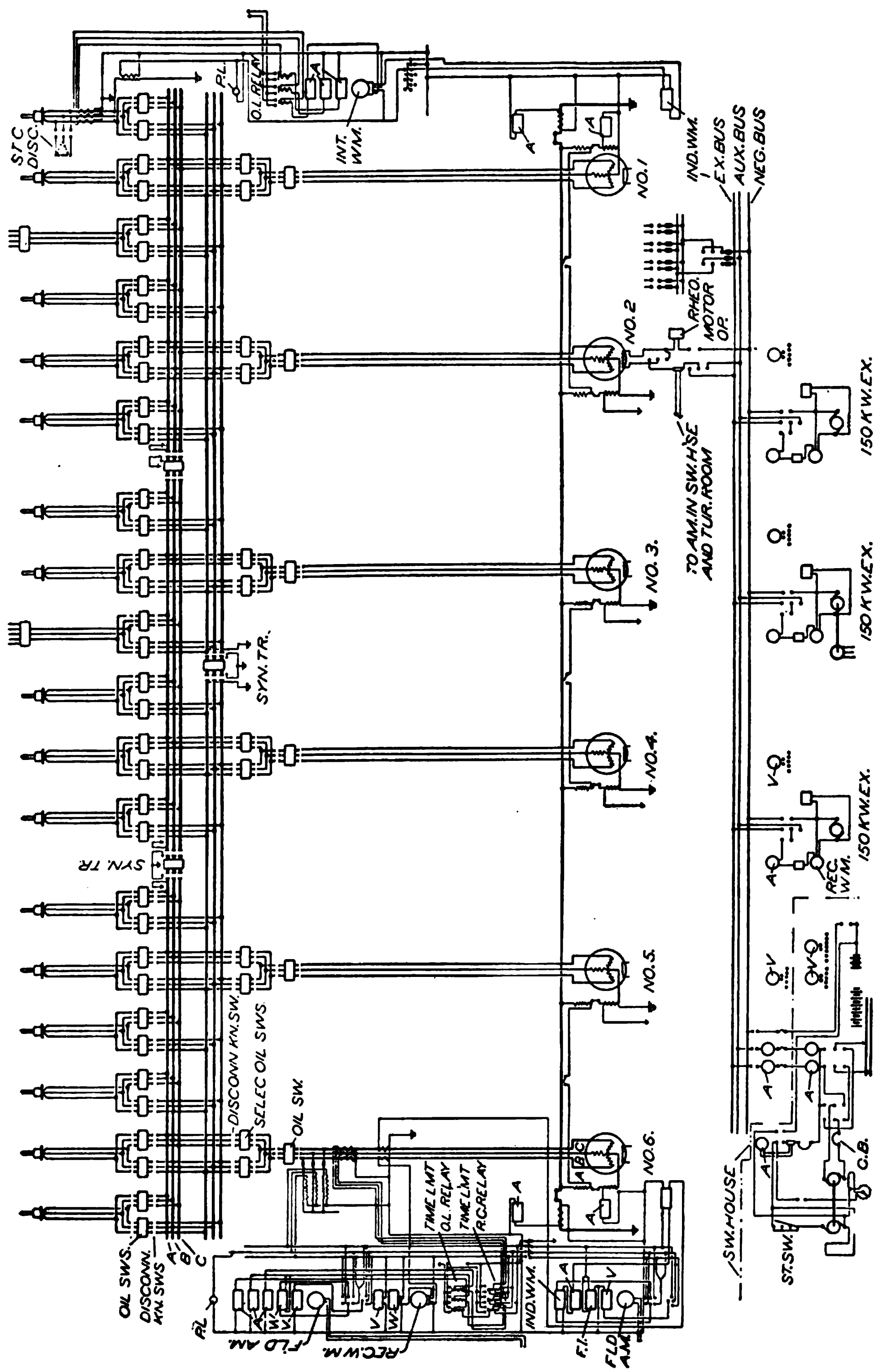


FIG. 6. Wiring Diagram, Port Morris Plant, New York (*The Engineer*).

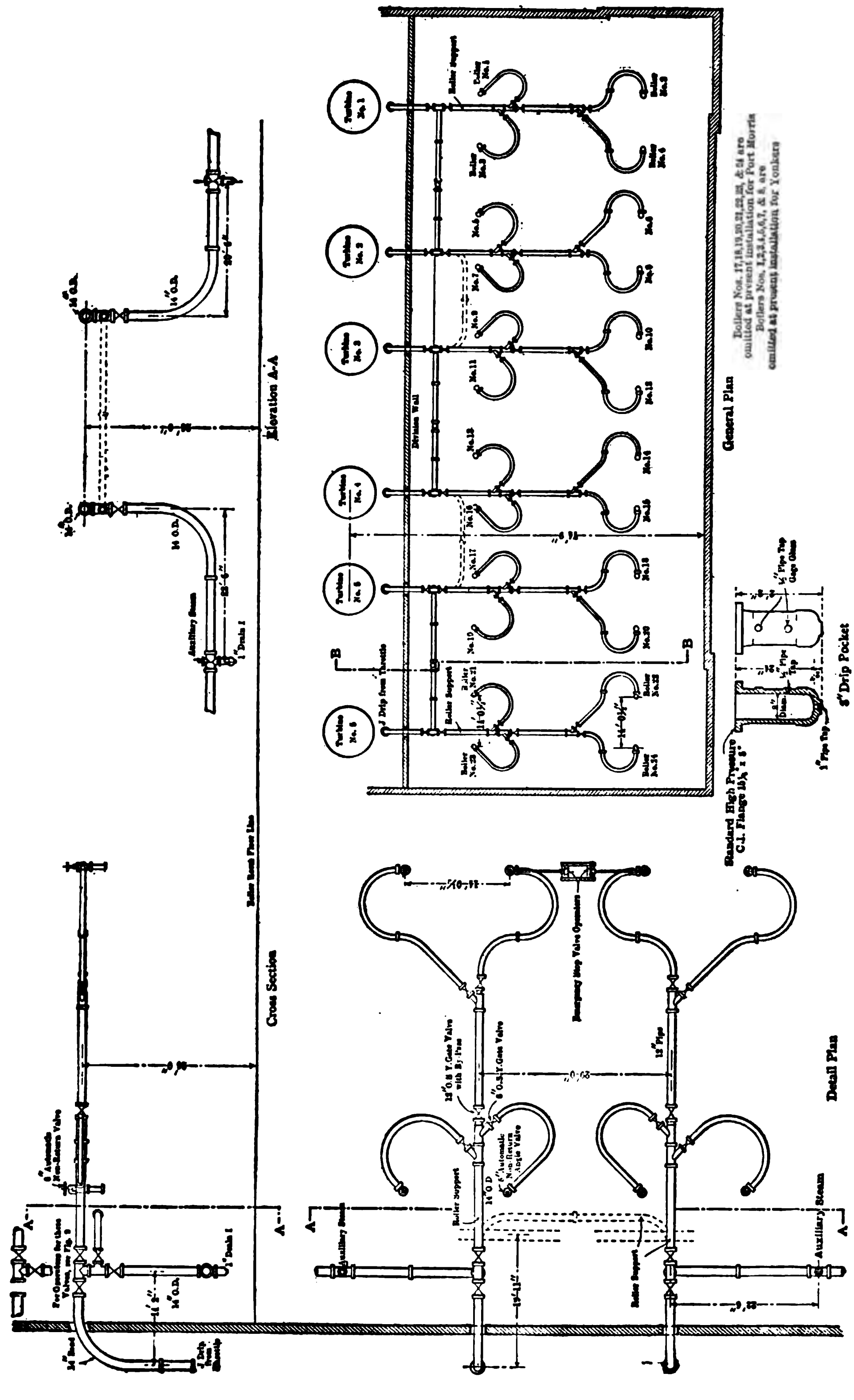


FIG. 7. Main Steam Piping, Port Morris Plant, New York (*Power*).

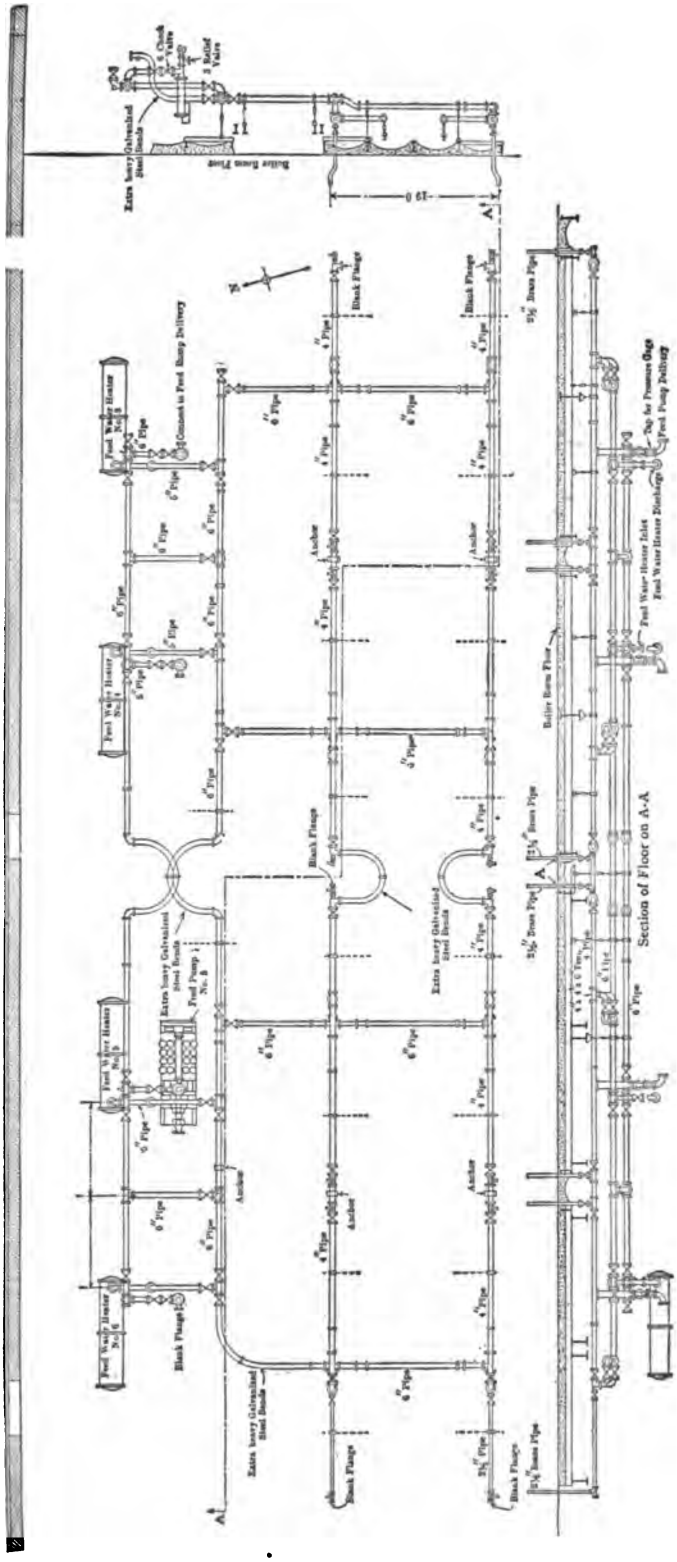
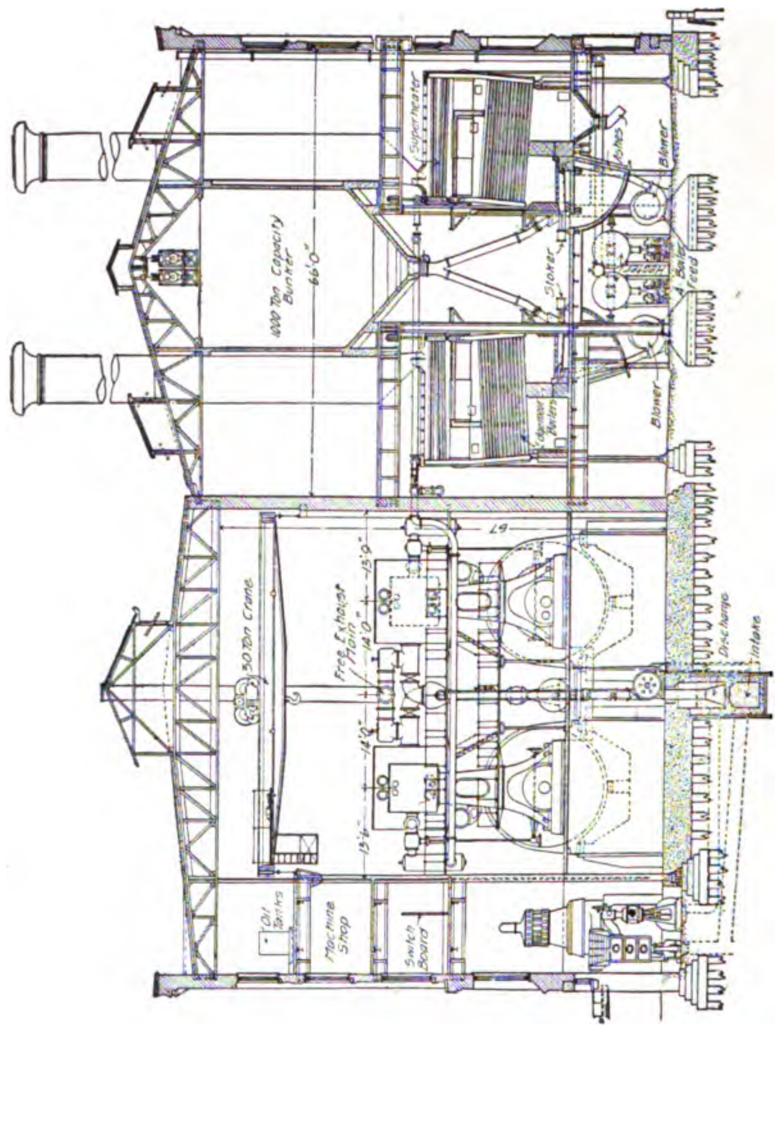


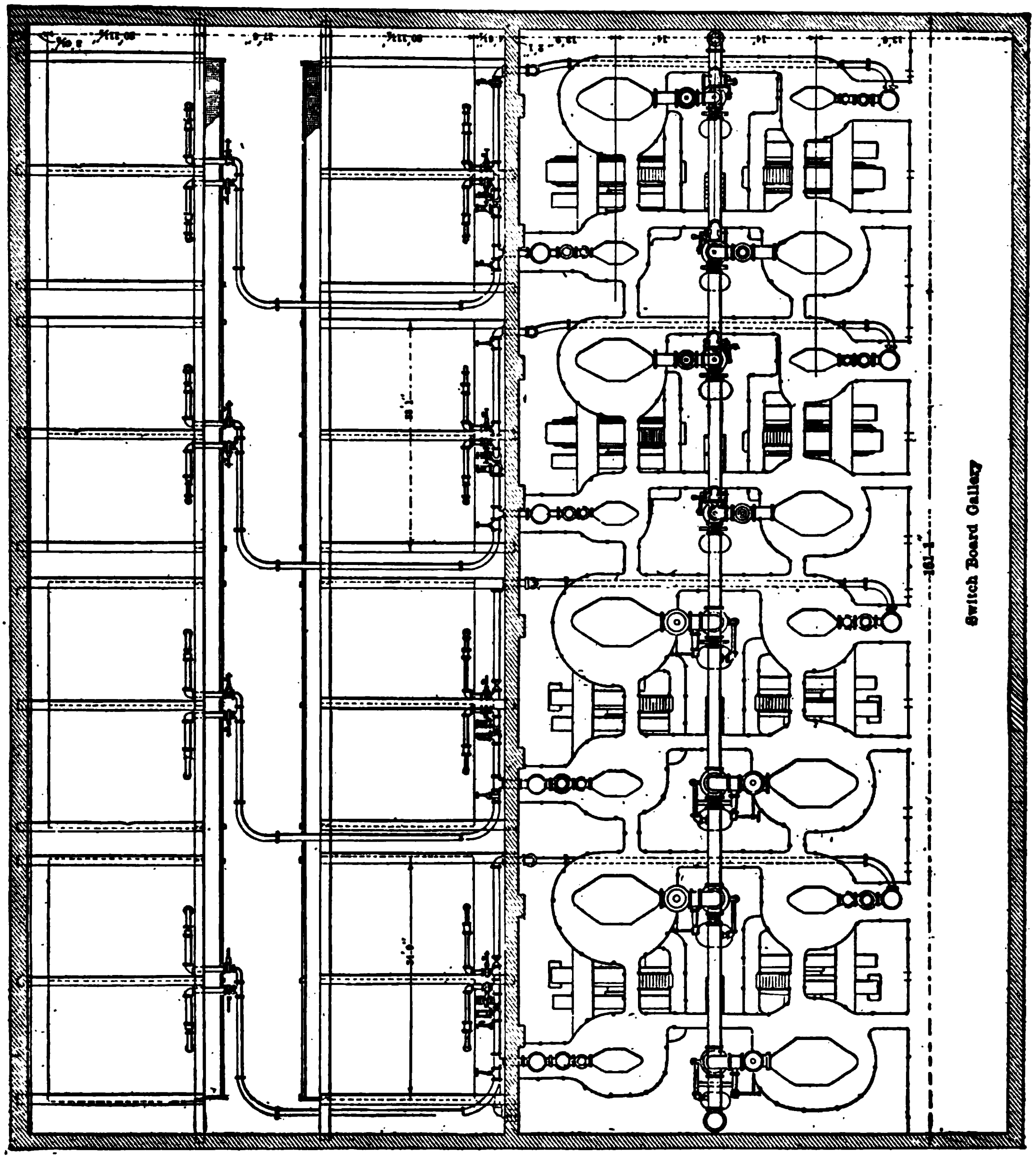
FIG. 8. Boiler Feed Piping, Yonkers Plant, New York (*Power*).

FIG. 9. Remote-Control Switchboard "Port Morris" Plant, New York.

Subject.		Remarks.
Building	165′ × 135′	
Boiler room	165′ × 81′	
Generator room	165′ × 54′	Including switch room, 20′ wide.
Boilers (16)	Stirling	
At present installed (8)	Stirling	
Size, each	4,350 sq. ft.	
Pressure	175 lb.	
Superheater	100° Fahr.	
Grate (chain)	145 sq. ft.	Extended furnace.
Steam Piping	6″, 10″ header	5″ auxiliary header.
Feed-Water Heaters (2)	5,000 H.P. each	Open type.
Feed Pumps (2)	14″ × 9″ × 12″	Duplex plunger.
" " (1)	14″ × 9″ × 12″	Future.
House Pumps (2)	8″ × 10¼″ × 10″	Duplex piston.
Coal Handling	Gantrie crane, 2-ton bucket	100 tons per hour.
Span	150′ 0″	Motor driven.
Coal Bins (16)	1.2 tons per lineal ft.	Reinforced concrete.
Conveyor	Narrow-gauge railway	Trolley locomotive.
Ash Handling	Standard and narrow-gauge ry.	Large sunk ash pit.
Chimneys (2)	radial brick,	
Height above grate	83′ 6″	Forced draft.
Diameter at top	9′ 0″	
Blowers	1 per 4 boilers	Engine, 9″ × 10″
Circulating Water.		
Intake	55 sq. ft.	Concrete.
Outlet	35 sq. ft.	"
Turbo-Generators (2)	2,000 K.W. each	G. E. Co., Curtis, 4 stage.
Turbo-Generators (3)	3,000 K.W. each	Future.
Phase	3	
Cycle	40	
Volt	2,300	
Speed	800 revolutions per minute	
Condensers	30″ elevated jet	16″ tail pipe.
Circulating pump	14″ centrifugal	Steam driven, horizontal.
Dry vacuum pump	10″ × 21″ × 12″	Rotative, single stage.
Exciters (2)	75 K.W. turbo-generators	Two-stage, horizontal, Curtis.
Speed	2,400 revolutions per minute	
Oil Pumps (2)	7½″ × 2¾″ × 10″	20 gallons per minute each.
Pressure	600 lb.	
Oil tank	1 filtering tank (1 future)	600 gallons per hour.
Crane	30 tons	54′ 3″ above generator floor.
Span	52′ 0″	



Cross-Section of Commerce St. Plant, Milwaukee (*Elec. Ry. Review*).



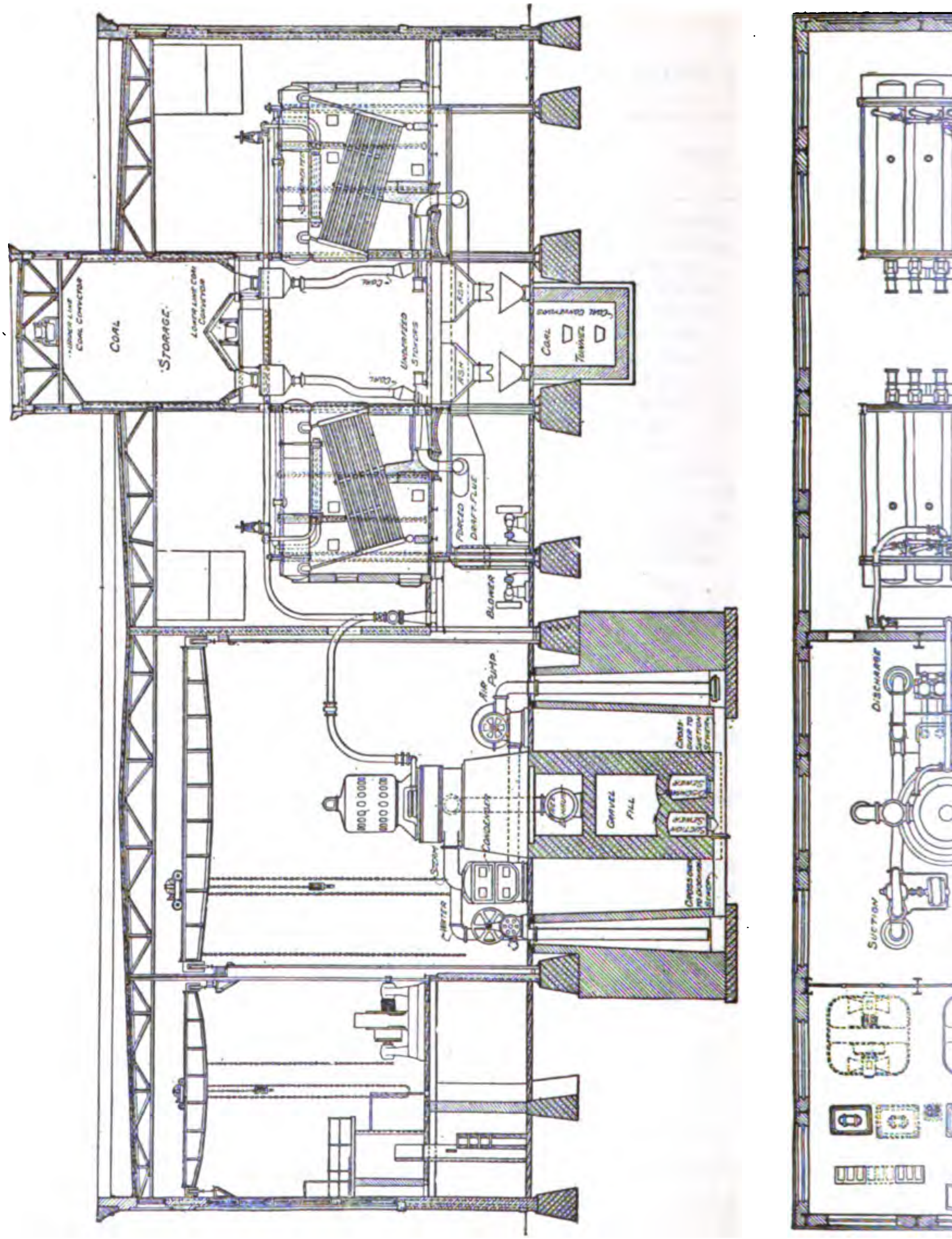
Plan of Commerce St. Plant, Milwaukee (*Street Railway Journal*).

BOILER HEATING SURFACE PER K.W. CAPACITY, NORMAL RATING, OF VARIOUS AMERICAN AND EUROPEAN PLANTS.

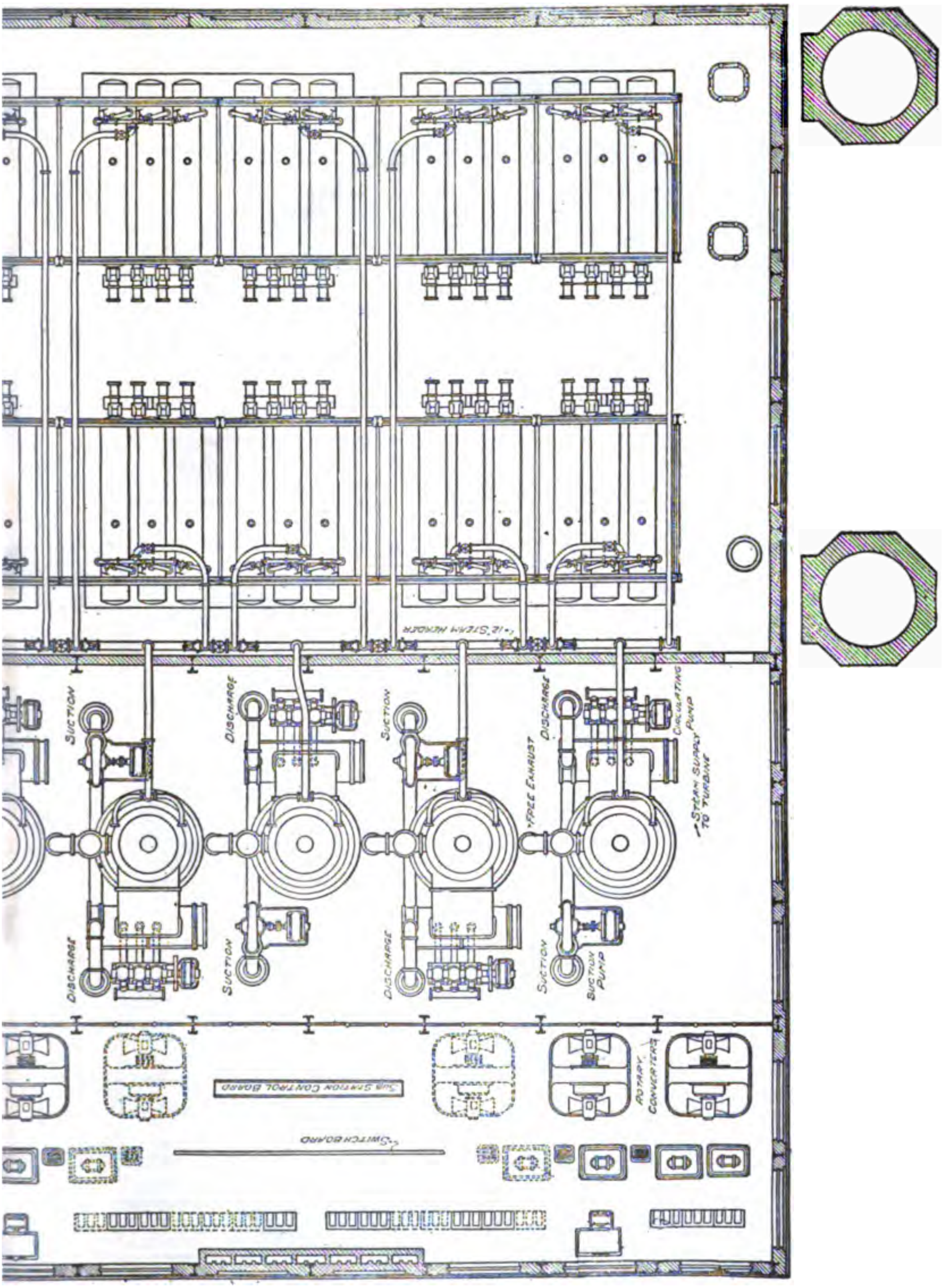
Name of Plant.	Square Feet Heating Surface per K.W.	Type of Prime Mover.	Service.
St. Denis, Paris	4.5	Turbines	Subway and lighting.
Chelsea, London	7.6	"	Subway and lighting.
Long Island City	7.6	"	Heavy railroading.
Waterside I, New York	6.5	"	Power and lighting.
Waterside II, "	8.0	"	Power and lighting.
Port Morris, "	5.0	"	Heavy railroading.
Yonkers, "	5.0	"	Heavy railroading.
59th Street, "	7.5	Engines	Subway railway.
74th Street, "	8.2	"	Elevated railway.
96th Street, "	6.7	"	Street railway.
Kingsbridge, "	5.6	"	Street railway.
L Street, Boston	8.2	Turbines	Power and lighting.
Potomac, Washington	5.1	"	Street railway and lighting.
D. and H., Mechanicville, New York	6.9	"	Street railway and power.
Bow Road, London	5.4	Engines	Power and lighting.
Municipal, Vienna	6.0	"	Power and lighting.
Delaware Avenue, Philadelphia	10.0	Turbines	Street railway.

COMPARISON OF AREA AND VOLUME OF VARIOUS AMERICAN AND EUROPEAN POWER HOUSES, PER K.W. CAPACITY.

Name of Plant.	Square Feet per K.W.	Cubic Feet per K.W.	Number of Boiler Floors.	Type of Prime Mover.
St. Denis, Paris	2.08	—	1	Turbines, horizontal.
Chelsea, London	1.51	142	2	" "
Long Island City	1.36	120	2	" "
Waterside I, New York	.95	110	2	" and engines, vertical.
Waterside II, "	0.80	108	2	" vertical and horizontal.
Port Morris, "	1.32	102	2	" vertical.
Yonkers, "	1.32	102	2	" "
59th Street, "	2.32	259	2	Engines, "
74th Street, "	2.05	222	2	" "
96th Street, "	1.40	170	3	" "
Kingsbridge, "	1.88	156	2	" "
L Street, Boston	2.45	148	1	Turbines, "
Fisk Street, Chicago	2.42	140	1	" "
Potomac, Washington	1.55	84	1	" "
D. and H., Mechanicville, N.Y.	2.22	130	1	" "
Bow Road, London	2.91	232	1	Engines, " and horizontal.



Plan and Cross-Section of Quincy Plant of the Massachu



setts Electric Companies (*Street Railway Review*).

APPENDIX.

METRIC SYSTEM OF WEIGHTS AND MEASURES.

The metric system is based upon the distance from the equator to the pole. Very approximately the ten millionth part of this arc was chosen as the unit of measures of length, and called a metre. The cube of the tenth part of the metre was adopted as the unit of capacity, and denominated a litre. The weight of a litre of distilled water at its greatest density was called a kilogram of which the thousandth part, or gram, was adopted as a unit of weight. The multiples of these, proceeding in decimal progression, are distinguished by the employment of the prefixes deca, hecto, kilo and myria (from the Greek), and the subdivision by deci, centi and milli (from the Latin).

METRIC MEASURES. ENGLISH EQUIVALENTS.

LENGTH.

Single Units.	Meters.	Inches.	Feet.	Yards.	Miles.
Millimeter..(mm.)=	.001	.03937	.00328	....	....
Centimeter..(cm.)=	.01	.39371	.03281	.01094	....
Decimeter..(dm.)=	.1	3.93708	.32809	.10936	....
Meter..........(M.)=	1.	39.37079	3.28090	1.09363	.00062
Decameter. (Dm.)=	10.	....	32.80899	10.93633	.00621
Hectometer(Hm.)=	100.	....	328.0899	109.3633	.06214
Kilometer..(Km.)=	1 000.	....	3280.899	1093.633	.62138
Myriameter(Mm.)=	10 000.	....	....	....	6.21382

SURFACE.

Single Units.	Sq. Meters.	Sq. Inches.	Sq. Feet.	Sq. Yards.	Sq. Miles.
Sq. Centimeter...=	.0001	.155	....	....	....
Sq. Decimeter....=	.01	15.501	.108	....	....
Ca.....(=Sq. m.)=	1.	1 550.059	10.764	1.196	....
Are...(=Sq. Dm.)=	100.	155 005.9	1076.43	119.603	....
Hectare=(SqHm.)=	10 000.	....	107643.	11960.33	....
Sq. Kilometer....=	1 000 000.	....	....	....	.38613

VOLUME.

Single Units.	Cu. Inches.	Cu. Feet.	Cu. Yards.	Liters.	U. S. Gals.
Cubic cm. (=ml.)=	.0610	....	....	.001	.00026
Cubic dm. (=liter)=	61.0271	.03532	.00131	1.	.26418
Cubic met. (=Kl.)=	61 027.06	35.3166	1.30802	1000.	264.179

WEIGHT.

Single Units.	Grams.	Oz. Avoir.	Lb. Avoir.	2000 lb. T. (Net Tons).	Troy Gr.
Milligram........=	.001	....	....	....	.0154
Gram............=	1.	.03527	.00221	....	15.4324
Kilogram ....=	11 000.	35.27394	2.20462	.001102	....
Tonne = .984g. T.=	1 000 000.	....	2204.6215	1.102311	....
1 gross T. = 2240 lb..					

TABLE OF GALLONS EQUIVALENT TO LITERS.

(U.S. Gallons of 8.33 lb.)

No.	Liters to Gallons Liquid.	Gallons to Liters Liquid.	Cubic Meters to Gallons Liquid.	Gallons to Cubic Meters Liquid.
1	0.2642	3.7854	264.17	0.0038
2	0.5284	7.5707	528.34	0.0076
3	0.7925	11.3561	792.51	0.0114
4	1.0567	15.1415	1056.68	0.0151
5	1.3209	18.9268	1320.85	0.0189
6	1.5851	22.7122	1585.02	0.0227
7	1.8492	26.4976	1849.19	0.0265
8	2.1134	30.2830	2113.36	0.0303
9	2.3776	34.0683	2377.53	0.0341

TABLE OF POUNDS PER CUBIC AND SQUARE EQUIVALENT TO KILOGRAMS PER CUBIC AND SQUARE

No.	Kilograms per Cubic Meter to Pounds per Cubic Foot.	Pounds per Cubic Foot to Kilograms per Cubic Meter.	Kilograms per Square Centimeter to Pounds per Square Inch.	Pounds per Square Inch to Kilograms per Square Centimeter.
1	0.0624	16.0192	14.2232	0.0703
2	0.1248	32.0385	28.4465	0.1406
3	0.1873	48.0577	42.6697	0.2109
4	0.2497	64.0769	56.8929	0.2812
5	0.3121	80.0962	71.1161	0.3515
6	0.3745	96.1154	85.3394	0.4218
7	0.4370	112.1346	99.5626	0.4922
8	0.4994	128.1539	113.7858	0.5625
9	0.5618	144.1731	128.0090	0.6328

TABLE OF CUBIC METERS AND CUBIC CENTIMETERS EQUIVALENT TO CUBIC FEET AND CUBIC INCHES.

No.	Cubic Centimeters to Cubic Inches.	Cubic Inches to Cubic Centimeters.	Cubic Meters to Cubic Feet.	Cubic Feet to Cubic Meters.	Cubic Meters to Cubic Yards.	Cubic Yards to Cubic Meters.
1	0.061	16.3934	35.316	0.0283	1.308	0.7645
2	0.122	32.7869	70.632	0.0566	2.616	1.5291
3	0.183	49.1803	105.948	0.0849	3.924	2.2936
4	0.244	65.5738	141.264	0.1133	5.232	3.0581
5	0.305	81.9672	176.580	0.1416	6.540	3.8226
6	0.366	98.3607	211.896	0.1699	7.848	4.5872
7	0.427	114.7541	247.212	0.1982	9.156	5.3517
8	0.488	131.1475	282.528	0.2265	10.464	6.1162
9	0.549	147.5410	317.844	0.2548	11.772	6.8807

KILOGRAMS PER METER AND SQUARE METER EQUIVALENT TO POUNDS PER FOOT AND SQUARE FOOT.

No.	Kilograms per Meter to Pounds per Foot.	Pounds per Foot to Kilograms per Meter.	Kilograms per Square Meter to Pounds per Square Foot	Pounds per Square Foot to Kilograms per Square Meter.
1	0.6720	1.4882	0.2048	4.8825
2	1.3439	2.9764	0.4096	9.7649
3	2.0159	4.4645	0.6144	14.6474
4	2.6879	5.9527	0.8193	19.5299
5	3.3598	7.4409	1.0241	24.4123
6	4.0318	8.9291	1.2289	29.2948
7	4.7037	10.4172	1.4337	34.1773
8	5.3757	11.9054	1.6385	39.0597
9	6.0477	13.3936	1.8433	43.9422

FOOT HORSE-POWER EQUIVALENT TO METRIC HORSE-POWER AND TON MEASURES.

No.	Horse-Power Metric to U.S.	Horse-Power U.S. to Metric.	Foot-Pounds to Kilogrammeters.	Kilogrammeters to Foot-Pounds.	Gross Tons per Square Foot to Metric Tons per Square Meter.	Metric Tons per Square Meter to Gross Tons per Square Foot.
1	0.986	1.014	0.1383	7.2329	10.937	0.091
2	1.973	2.028	0.2765	14.4659	21.873	0.183
3	2.959	3.042	0.4148	21.6988	32.810	0.274
4	3.945	4.056	0.5530	28.9317	43.747	0.366
5	4.932	5.069	0.6913	36.1646	54.684	0.457
6	5.918	6.083	0.8295	43.3976	65.620	0.549
7	6.904	7.097	0.9678	50.6305	76.557	0.640
8	7.890	8.111	1.1061	57.8634	87.494	0.731
9	8.877	9.125	1.2443	65.0963	98.431	0.823

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SUBSTANCES.

Based on Pure Water at 62° Fahr., Barometer 30". Weight of One Cubic Foot, 62.355.	Average Specific Gravity Water = 1.	Average Weight of One Cu. Ft. Pounds.
Air at 60 degrees Fahr. atmospheric pressure (14.7 lbs. per sq. in.) weights $\frac{1}{815}$th of water	.00123	.0765
Ash, dry, of soft coal	—	35 to 45
Asphaltum	1.4	87
Brass, cast	8.1	505
Brass, rolled	8.4	524
Brickwork, common and hard	—	125
Brickwork, fire brick	—	150
Coal, anthracite	—	52 to 60
Coal, bituminous, solid	—	79 to 84
Coal, bituminous, broken, loose	—	47 to 52
Coke	—	23 to 32
Concrete, average	—	135 to 145
Concrete, cinder	—	80
Earth, dry, loose	—	72 to 90
Earth, wet, packed	—	90 to 110
Gneiss	2.69	168
Granite	2.72	170
Iron, cast	7.15	446
Iron, wrought	7.69	480
Oak, white, dry	.77	48
Pine, yellow	.55	34.3
Pitch	1.15	71.7
Sand, dry	—	90 to 106
Sandstone	—	151
Snow	—	5 to 12
Slate	2.8	175
Steel	7.85	490
Tar	1	62.35
Water, at 32 degrees	1	62.35

TABLE OF INCHES AND FEET EQUIVALENT TO MILLIMETERS AND METERS.

No.	64ths of an Inch to Millimeters.	Millimeters to 64ths of an Inch.	Inches to Centimeters.	Centimeters to Inches.	Meters to Feet.	Feet to Meters.
1	0.3969	2.5197	2.54	0.3937	3.2808	0.3048
2	0.7938	5.0394	5.08	0.7874	6.5617	0.6096
3	1.1906	7.5590	7.62	1.1811	9.8425	0.9144
4	1.5857	10.0787	10.16	1.5748	13.1233	1.2192
5	1.9844	12.5984	12.70	1.9685	16.4042	1.5240
6	2.3813	15.1181	15.24	2.3622	19.6850	1.8288
7	2.7781	17.6378	17.78	2.7559	22.9658	2.1336
8	3.1750	20.1574	20.32	3.1496	26.2467	2.4384
9	3.5719	22.6771	22.86	3.5433	29.5275	2.7432

TABLE OF SQUARE INCHES AND SQUARE FEET EQUIVALENT OF SQUARE CENTIMETERS AND SQUARE METERS.

No.	Square Inches to Square Centimeters.	Square Centimeters to Square Inches.	Square Feet to Square Meters.	Square Meters to Square Feet.	Square Yards to Square Meters.	Square Meters to Square Yards
1	6.4516	0.155	0.0929	10.7639	0.8361	1.196
2	12.9032	0.310	0.1858	21.5278	1.6722	2.392
3	19.3548	0.465	0.2787	32.2917	2.5084	3.588
4	25.8064	0.620	0.3716	43.0556	3.3445	4.784
5	32.2581	0.775	0.4645	53.8194	4.1806	5.980
6	38.7097	0.930	0.5574	64.5833	5.0167	7.176
7	45.1613	1.085	0.6503	75.3472	5.8528	8.372
8	51.6129	1.240	0.7432	86.1111	6.6890	9.568
9	58.0645	1.395	0.8361	96.8750	7.5251	10.764

TABLE OF POUNDS AND NET TONS EQUIVALENT TO KILOGRAMS AND METRIC TONS

No.	Avoirdupois Pounds to Kilograms.	Kilograms to Pounds Avoirdupois.	Net Tons to Metric Tons.	Metric Tons to Net Tons.	Gross Tons to Metric Tons.	Metric Tons to Gross Tons.
1	0.4536	2.2046	0.9072	1.1023	1.0161	0.9842
2	0.9072	4.4092	1.8144	2.2046	2.0321	1.9684
3	1.3608	6.6138	2.7216	3.3069	3.0482	2.9526
4	1.8144	8.8184	3.6288	4.4092	4.0642	3.9368
5	2.2680	11.0230	4.5360	5.5115	5.0803	4.9210
6	2.7216	13.2276	5.4432	6.6138	6.0963	5.9052
7	3.1752	15.4322	6.3504	7.7161	7.1124	6.8894
8	3.6288	17.6368	7.2576	8.8184	8.1285	7.8736
9	4.0824	19.8414	8.1647	9.9207	9.1445	8.8578

UNITS OF WEIGHTS AND MEASURES.—VOLUME.

Units.	Cubic Inches.	Cubic Feet.	Cubic Centimeters.	Liters.	Remarks.
Cubic Measure.					
1 cubic inch =	1	.00058	16.387	.016387	.03613 lb. H_2O @ 4° C.
1 728 cu. in. = 1 cu. foot =	1 728	1	28 315	28.315	62.425 lb. H_2O @ 4° C.
27 cu. ft. = 1 cu. yd. =	46 656	27	764 552	764.552	.76455 cu. meters.
Liquid Measure, U. S.					
1 gill =	7.219	....	118.29	.11829	
4 gills = 1 pint =	28.875	....	473.18	.47318	
2 pints = 1 quart =	57.75	.0334	946.36	.94636	
4 quarts = 1 gallon =	231.	.1337	3 785.43	3.7854	8.34 avoir. lb. H_2O @ 4° C.
1 English Imp. gallon =	277.27	.1605	4 543.46	4.54346	10 avoir. lb. H_2O @ 62° F.
Dry Measure.					
1 pint =	33.6	.0194	550.6	.5506	
2 pints = 1 quart =	67.2	.0389	1 101	1.101	
4 quarts = 1 gallon =	268.8	.1556	4 405	4.405	
8 quarts = 1 peck =	537.61	.3111	8 810	8.81	
4 pecks = 1 bushel =	2 150.42	1.2445	35 240	35.24	77.69 avoir. lb. H_2O @ 4° C.
Fluid Measure.					
1 minim =	.00376	....	.0616	.0000616	U. S. Measures.
60 minims ≐ 1 drachm =	.2256	....	3.7	.0037	
8 drachms = 1 ounce =	1.8047	....	29.57	.0296	456. gr. H_2O @ 4° C.
16 ounces = 1 pint =	28.875	....	473.18	.47318	
8 pints = 1 gallon =	231	....	3 785.44	3.785	
Metric System.					
1 cubic centimeter =	.06102	.000035	1	.001	1 g. H_2O @ 4° C.
1 000 cu. cm. = 1 cu. dm =	61.02	.0353	1 000	1	1 ml. = 1 c. c. = .061 cu. in.
1 000 cu.dm. = 1 cu.meter =	61 022	35.317	1 000 000	1 000	1.308 cu. yd.
Miscellaneous.					
1 perch of stone =	....	24.75	....	.70 cu.m.	16.5′ x 1.5′ x 1′
1 cord of wood =	....	128	....	3.63 "	4′ x 4′ x 8′
1 barrel (not fixed) ≐	7 689	4.45	....	....	3.58 bush., 17″ diam. of head
1 hogshead (=63 U.S.l.g.) =	14 553	8.12	....	238.5 liters.	x 19″ diam. at bung x 28″
1 foot board measure =	144	.0833	....	.0024 cu. m.	length.

UNITS OF WEIGHTS AND MEASURES.—LENGTH AND SURFACE.

LENGTH.

Units.	Inches.	Feet.	Yards.	Rods.	Miles.	mm.	cm.	Meters.	Km.
1 Mil....	.001	....	....	....	....	.0254	.00254	....	....
1 Inch...	1.	.0833	.0278	.00505	.000016	25.4001	2.54001	.0254	.000025
1 Foot..	12.	1.	.3333	.06061	.000189	304.801	30.480	.3048	.000305
1 Yard..	36.	3.	1.	.18182	.000568	914.4	91.44	.9144	.000914
1 Rod...	198.	16.5	5.5	1.	.00313	5029.2	502.92	5.0292	.00503
1 Chain..	792.	66.	22.	4.	.0125	....	2011.68	20.117	.02012
1 Mile...	63360.	5280.	1760.	320.	1.	....	....	1609.347	1.60935
1 Knot..	....	6080.20	2026.73	368.502	1.15155	....	....	1853.248	1.85325
1 mm...	.03937	.00328	.0011	.0002	.000006	1.	.1	.001	.000001
1 cm.....	.39371	.0328	.0109	.00199	....	10.	1.	.01	.00001
1 Met...	39.37079	3.28083	1.094	.199	.000621	1 000.	100.	1.	.001
1 Km...	....	3280.83	1093.61	198.8387	.62137	1 000 000.	100 000.	1 000.	1.000

SURFACE.

Units.	Sq. Inches.	Sq. Feet.	Sq. Yards.	Acres.	Sq. Miles.	Sq. mm.	Sq. cm.	Sq. Meters.	Sq. Km.
1 Cir. Mil	.000786	....	....	....	....	.000506	....	....	....
1 Sq. Mil	.000001	....	....	....	....	.000645	.0000065	....	....
1 Sq. In.	1	.00694	.00077	....	....	645.163	6.452	.000645	....
1 Sq. Ft.	144	1.	.11111	.0000229	....	92 903.4	929.034	.092903	....
1 Sq. Yd.	1 296	9.	1.	.0002066	....	....	8361.31	.8361	....
1 Sq. Rod	39 204	272.25	30.25	.00625	.0000098	....	....	25.292	.000025
1 Acre	6 272 640	43 560.	4840.	1.	.00156	....	....	4 046.87	.004047
1 Sq. Mile	....	27 878 400	3 097 600	640.	.1	....	....	2 589 999.	2.59
1 Sq. mm.	.001550	.0000108	....	....	....	1.	.01	....	....
1 Sq. cm.	.1550.	.001076	....	....	....	100.	1.	.0001	....
1 Sq. M.	1 550.	10.764	1.196	.000247	....	1 000 000.	10 000.	1.	.000001
1 Sq. Km.	....	10 763 867.	1 195 985.	247.104	.386101	....	....	1 000 000.	1.

UNITS OF WEIGHTS AND MEASURES.—WEIGHT.

Units.	Ounces Avoir.	Pounds Avoir.	Grams.	Kilog.	Remarks.
Avoirdupois.					
1 dram =	.0625	.0039	1.772	....	27.34 grains.
16 drams = 1 ounce =	1	.0625	28.35	.0284	437.5 "
16 ounces = 1 pound =	16	1	453.59	.4536	Wt. of 27.7 cu. in. H_2O @ 4° C.
112 pounds = 1 cwt. =	1 792	112	50 802	50.802	1 lb. avoir. = 1.2153 lb. Troy.
20 cwt. = 1 ton (long).	35 840	2 240	....	1 016.05	Long ton is the only English ton.
Troy.					
1 grain =	.00228	.000143	.0648	.000065	All grains on this sheet are alike,
24 grains = 1 dwt. =	.05472	.00343	1.555	.001555	
20 dwt. = 1 ounce =	1.097	.06857	31.104	.0311	
12 ounces = 1 pound =	13.166	.82286	373.25	.373	
Apothecaries'.					
1 grain =	.00228	.000143	.0648	.000065	Pound, ounce and grain same as [Troy.
20 grains = 1 scruple =	.0456	.00286	1.296	.001296	
3 scruples = 1 dram =	.1368	.00858	3.888	.003888	
8 drams = 1 ounce =	1.097	.06857	31.104	.0311	45 drops = 1 fluid dram.
12 ounces = 1 pound =	13.166	.82286	373.24	.373	2 tablespoonfuls = 1 ounce.
Metric.					
1 milligram =	.0000353	.0000022	.001	.000001	
1 gram =	.035274	.002205	1.	.001	Wt. 1 cu. cm. H_2O @ 4° C.
1 kilogram =	35.274	2.20462	1 000	1.	Wt. 1 litre H_2O @ 4° C. (39° F.)
1 000 kilog. = 1 Tonne. =	35 274	2 204.62	1 000 000	1 000	
Miscellaneous.					
1 bushel wheat =	....	60	....	....	
1 bushel oats =	....	32	....	....	
21 cu. ft. sand, dry and shaken =	....	2 240	....	....	
28 " clay, dry, average =	....	2 240	....	....	
1 " anthracite coal, loose =	....	50 to 55	....	....	41 to 45 cu. ft. per gr. ton broken.
1 " bituminous " " =	....	40 to 50	....	....	Bushel = 70 to 80 lbs. average.
1 cord pine, white or Norway =	....	2 000	....	....	

UNITS OF WEIGHTS AND MEASURES.—MISCELLANEOUS.

Units.	Value and Relation of Units.
Time.	
1 Second. . . . . =	$\frac{1}{86164.09}$ sidereal day, or $\frac{1}{86400}$ mean solar day. Swing of pendulum 39.0958" long at Washington.
1 Minute. . . . . =	60 seconds.
1 Hour. =	60 minutes, 3 600 seconds.
1 Year. =	365 days + 5 hrs. + 48 min. + 48 sec.
Velocity.	
1 Centimeter per second. . . . . =	.39 in. per sec. = .0328 ft. per sec.
1 Meter " " . . . . . =	100 cm. per sec. = 3.28 feet per sec.
1 Foot " " . . . . . =	.3048 meters per sec. = .682 miles per hour.
1 Mile " hour. . . . . . . =	.447 " " = 1.466 feet per sec.
Acceleration.	
1 Centimeter per sec. per sec. . =	.0328 feet per sec. per sec. Of gravity = 981. cm. per sec. per sec.
1 Foot per sec. per sec. . . . . . . =	30.48 cm. " " " " = 32.2 ft. " "
1 Mile per hr. per sec. . . . . =	1.466 feet " " " " = 21.9 miles per hr. per sec.
Force.	
1 Dyne = $\frac{1}{981}$ gram. . . . . =	Gives 1 gram vel. of 1 cm. per sec. in 1 sec. = .00000225 lb.
1 Poundal = $\frac{1}{32.187}$ pound. . . =	" 1 pound " " 1 ft. " " = .0311 16.
1 Pound. . . . . =	32.187 poundals = 445 177 dynes.
Work.	
1 Erg. . . . . =	1 dyne acting through 1 cm. = $\frac{1}{981}$ gram centimeters.
1 Foot pound. . . . . =	1 pound " " 1 foot = 13 560 000 ergs.
Power.	
1 Erg per second. . . . . =	Rate of work, overcoming force of 1 dyne through 1 cm. per sec.
1 Watt. . . . . =	10 000 000 ergs per second = $\frac{1}{746}$ horse-power.
1 Horse-power (Eng. & Am.) . =	33 000 ft. lb. per minute = 746 Watts. = 1.01385 chevaux-vapeur.
1 Cheval-vapeur(Mt.Fr.or G.) =	75 kgm. per sec. = 735.7 Watts = .9863 H.P. = 32 548 ft. lb. per minute.
1 Austrian H. P. . . . . =	33 034 ft. lb. per min. = 76.1 kgm. per sec. = 1.001 Eng. H. P.

UNITS OF WEIGHTS AND MEASURES.—MISCELLANEOUS.

Units.	Value and Relation of Units.
Heat.	
1 Calorie (French) .... =	Heat required to raise 1 gram of water 1° C. = 41 600 000 ergs.
1 British Thermal Unit ...... =	" " " " 1 lb. " " 1° F. = 778 ft. lb. = 252 calories.
Light.	
1 Candle power .... =	Light of candle weighing $\frac{1}{6}$ lb., burning 120 grains in one hour.
1 Bec Carcel (French) .... =	9.5 Standard candles.
Illumination.	
1 Candle foot. .... =	Illumination of 1 candle power at distance of 1 foot.
Temperature.	
1 Degree Centigrade .... =	$\frac{1}{100}$ rise in temp. from freezing to boiling point of water. Equal to 1.8° F. 0° C. = temperature of freezing water.
1 Degree Fahrenheit .... =	$\frac{1}{180}$ rise in temp. from freezing to boiling point of water. Equal to $\frac{5}{9}$° C. 0° C. = 32° F. above temp. of mixture of 1 wt. salt and 2 wt. snow.

Pressure.	Atmospheres.	Kilograms per sq. meter.	Kilograms per sq. cm.	Grams per sq. cm.	Pounds per sq. ft.	Pounds per sq. in.
1 Atmosphere .... =	1	10 330	1.033	1 033	2 116	14.7
1 Kilogram per sq. meter. ... =	.000097	1	.0001	.1	.205	.00142
1 " " cm. .... =	.968	10 000	1	1 000	2 048	14.2
1 Dyne per sq. cm. .... =	......	......	......	.00102	0021	....
1 Pound per sq. foot .... =	.00047	4.88	.000488	.488	1	.00695
1 " " in. .... =	.0681	703	.0703	70.3	144	1

DECIMALS OF A FOOT, EQUIVALENT TO INCHES AND FRACTIONS OF AN INCH.

(Kent.)

Inches.	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	0	.01042	.02083	.03125	.04167	.05208	.06250	.07292
1	.0833	.0938	.1042	.1146	.1250	.1354	.1458	.1563
2	.1667	.1771	.1875	.1979	.2083	.2188	.2292	.2396
3	.2500	.2604	.2708	.2813	.2917	.3021	.3125	.3229
4	.3333	.3438	.3542	.3646	.3750	.5854	.3958	.4063
5	.4167	.4271	.4375	.4479	.4583	.4688	.4792	.4896
6	.5000	.5104	.5208	.5313	.5417	.5521	.5625	.5729
7	.5833	.5938	.6042	.6146	.6250	.6354	.6458	.6563
8	.6667	.6771	.6875	.6979	.7083	.7188	.7292	.7396
9	.7500	.7604	.7708	.7813	.7917	.8021	.8125	.8229
10	.8333	.8438	.8542	.8646	.8750	.8854	.8958	.9063
11	.9167	.9271	.9375	.9479	.9583	.9688	.9792	.9896

DECIMAL INCHES AND MILLIMETERS EQUIVALENT TO FRACTIONS OF AN INCH.

Inches.		Millimeters.	Inches.		Millimeters.	Inches.		Millimeters.
1/64	.0156	.397	11/32	.3438	8.73	43/64	.6719	17.07
1/32	.0313	.79	23/64	.3594	9.13	11/16	.6875	17.47
3/64	.0469	1.19	3/8	.3750	9.53	45/64	.7031	17.86
1/16	.0625	1.59	25/64	.3906	9.92	23/32	.7188	18.26
5/64	.0781	1.98	13/32	.4063	10.32	47/64	.7344	18.66
3/32	.0938	2.38	27/64	.4219	10.72	3/4	.7500	19.05
7/64	.1094	2.78	7/16	.4375	11.12	49/64	.7656	19.45
1/8	.1250	3.18	29/64	.4531	11.51	25/32	.7813	19.85
9/64	.1406	3.57	15/32	.4688	11.91	51/64	.7969	20.25
5/32	.1563	3.97	31/64	.4844	12.31	13/16	.8125	20.64
11/64	.1719	4.37	1/2	.5000	12.70	53/64	.8281	21.04
3/16	.1875	4.76	33/64	.5156	13.10	27/32	.8438	21.44
13/64	.2031	5.16	17/32	.5313	13.50	55/64	.8594	21.83
7/32	.2188	5.56	35/64	.5469	13.89	7/8	.8750	22.23
15/64	.2344	5.95	9/16	.5625	14.29	57/64	.8906	22.63
1/4	.2500	6.35	37/64	.5781	14.69	29/32	.9063	23.02
17/64	.2656	6.75	19/32	.5938	15.09	59/64	.9219	23.42
9/32	.2813	7.15	39/64	.6094	15.48	15/16	.9375	23.82
19/64	.2969	7.54	5/8	.6250	15.88	61/64	.9531	24.22
5/16	.3125	7.94	41/64	.6406	16.28	31/32	.9688	24.61
21/64	.3281	8.34	21/32	.6563	16.67	63/64	.9844	25.01

1 in. = 25.40 mm. = 2.54 cm.

INDEX.

A.

Ados (Sarco) CO_2 Recorder, 116.
Air pump, 266.
Air required, combustion, 113.
Analysis of coal, 111.
Anchors, piping, 189.
Appendix, 437.
Architectural features, 69.
    boiler room, 80.
    crane, 76.
    chimneys, 83.
    conclusion, 83.
    doors, 76.
    floors, 76.
    galleries, 78.
    review, 69.
    switchboard, 80.
    walls, 78.
    windows, 76.
Area of condenser water tunnels, 39.
    of power houses per K.W. capacity, 436.
    of screens, 39.
Ash handling system, 59th Street Plant, New York, 351.
    St. Denis plant, Paris, 340.
Ashes, removal, 82.
Automatic damper regulator, 133.
Auxiliaries, steam consumption of, 263.
Auxiliary buildings, 26.
Auxiliary electrical equipment, Chelsea Plant, London, 370.
    St. Denis Plant, Paris, 346.

B.

Baffle wall, chimneys, 146.
Base, column, 64.
Battery, storage, 290.
Beams, floor, 65.
Bearing power of soil, 44.
Bedplate, grouting, 48.
Blower, steam, 130.
Boiler, Babcock & Wilcox, 93.
    blow-off piping, 216.
    corrosion of, 148.
    durability of, 88.
    efficiency of, 9.
    foreign types, 99.
    grate surface, 88.
    heating surface per K.W. capacity, 436.
Boiler, feed piping, 215.
    pumps, 268.
Boiler feed water, 148.
    impure, 148.
    mud, 149.
    plant, 59th Street, New York, 355.
    plant, St. Denis, Paris, 342.
    plant, Twin Municipal, Vienna, 387.
    pure, 148.
    purifier, 150.
    scum, 150.
    storage, 154.
Boiler house, 17.
    architectural features, 80.
Boiler room equipment, St. Denis, Paris, 341.
    Fisk Street, Chicago, 373.
    Twin Municipal, Vienna, 387.
    safety, 86.
    scale, 149.
    setting, 91.
    size, 92.
    Stirling, 95.
    simplicity, 88.
Boiler tests, 318.
    method of, 319.
    trimmings, 92.
    types, 85.
    water circulation, 88.
    Wickes, 97.

Building, 48.
auxiliary, 26.
doors, 53.
elevators, 56.
floors, 48.
frame, structural steel, 61.
heating, 58.
lighting, 58.
material, 48.
plumbing, 56.
stairways, 56.
toilets, 56.
ventilating of, 53.
walls, 52.
windows, 52.
Bunker fires, 38.
Bunker, overhead, 36.
Bus-bar chambers, 285.

C.

CO_2 recorders, 115.
Central condenser, 252.
Chain grate stoker, 102.
Chelsea Plant, London, 361.
auxiliary electrical equipment, 370.
boilers, 365.
chimneys, 366.
circulating water supply, 361.
coal handling system, 362.
condenser plant, 367.
dimensions and data, 416.
economizers, 365.
exciters, 368.
feed water, 365.
oil cooling system, 368.
piping, 367.
substructure, 361.
superstructure, 362.
switching room, 369.
turbo-generators, 366.
wiring system, 370.
Chimneys, 83, 136.
baffle wall, 146.
character of, 136.
Chelsea Plant, London, 366.
draft, 121.
guyed, 144.
Chimneys — *continued.*
ladders, 146.
lightning arresters, 147.
lining of, 145.
Long Island City Plant, 146.
material of, 136.
radial brick, 139.
reinforced concrete, 140.
self supporting, 145.
steel, 142.
Twin Municipal Plant, Vienna, 392.
59th Street Plant, New York, 139.
Circulating water, piping, 220.
pumps, 264.
Chelsea Plant, London, 361.
59th Street Plant, New York, 351.
Twin Municipal Plant, Vienna, 385.
Closed feed-water heater, 156.
Coal, 104.
analysis, 111.
character of, 110.
Coal handling system, Chelsea Plant, London, 362.
59th Street, New York, 351.
St. Denis, Paris, 340.
Twin Municipal, Vienna, 384.
Coal, heat value of, 105.
piles, exposed, 28.
supply, 9.
Coal storage plants, 26, 82.
character of, 30.
comparison of, 35.
description of, 30.
Hamburg, Germany, 34.
Metropolitan Co., London, 34.
Shadyside, New York, 31.
Twin Municipal, Vienna, 34, 384.
Column Base, 64.
Columns, Types, Structural steel, 62.
Combustion, 113.
air required, 113.
recorders, CO_2, 115.
spontaneous, 29.
Complete unit system, 17.
Compound engines, 227.
Concrete mat construction, 42.
forms, 47.

Concrete mat construction — *continued.*
mixture of, 47.
piles, 43.
Condenser, 240.
application of, 244.
central, 252.
classification of, 244.
jet, 246.
principle of, 240.
surface, 248.
Condenser plant, Chelsea Plant, London, 367.
59th Street, New York, 358.
Fisk Street, Chicago, 377.
St. Denis, Paris, 344.
Twin Municipal, Vienna, 384.
Condenser water required, 244.
scarcity of, 40.
shut-off gates, 39.
supply of, 38.
Condenser water tunnels, 38.
arrangement of, 39.
Cooling ponds, 258.
towers, 254.
Corrosion, boiler, 148.
Cost of land, 11.
of power plants, 4.
Covering, high-pressure piping, 213.
architectural features of, 76.
low-pressure piping, 221.
Crane, runway of structural steel, 61.
Twin Municipal Plant, Vienna, 394.
59th Street Plant, New York, 361.

D.

Dampers, automatic regulator, 133.
of smoke flues, 133.
D. & H. Co. Plant, Mechanicville, N. Y., dimensions and data, 433.
Design of small plants, 22.
Distribution, current, 9.
Doors, 53.
architectural features, 76.
of smoke flues, 133.
Draft, 119.
chimney, 121.
Draft — *continued.*
meaning of, 119.
forced, 127.
induced, 128.
mechanical, 127.
production of, 120.
loss of, 120.
Drip piping, 210.
Drips, exhaust piping, 220.

E.

Economizers, 157.
Chelsea Plant, London, 365.
Efficiency of boilers, 90.
of power plants, 2.
Electric or steam driven pumps, 262.
Electrical equipment, 274.
Chelsea Plant, London, 370.
Fisk Street Plant, Chicago, 380.
introductory, 274.
59th Street Plant, New York, 359.
St. Denis Plant, Paris, 346.
Elevators, 56.
Employee's advantages, Fisk Street Plant, Chicago, 381.
Engines, comparison with turbines, 222.
compound, 227.
59th Street Plant, New York, 337.
house, 21.
quadruple expansion, 230.
tests of, 325.
triple expansion, 229.
Twin Municipal Plant, Vienna, 392.
simple, 226.
Excavation, 41.
Exciters, 278.
Chelsea Plant, London, 368.
Twin Municipal Plant, Vienna, 394.
59th Street Plant, New York, 359.
Exhaust piping, drips of, 220.
fittings of, 218.
material of, 218.
size of, 217.
Expansion of pipes, 188.
Expansion joints, smoke flues, 132.
structural steel, 64.
Extension, space for future, 11.

F.

Feed-water heaters, 154.
closed type, 156.
economizer, 157.
open type, 154.
percentage of gain, 160.
Feed-water plant, St. Denis Plant, Paris, 342.
Fiber stresses in structural steel, 64.
Fifty-ninth Street Plant, New York, 349.
boilers, 354.
circulating water system, 351.
coal and ash handling system, 351.
condenser plant, 358.
cranes, 361.
dimensions and data, 406.
electrical equipment, 359.
feed-water supply, 355.
oiling system, 361.
prime movers, 357.
removal of gases, 354.
steam piping, 355.
turbo-generators, 359.
Filtering tanks, oil, 269.
Fire, bunker, 38.
pumps, 268.
Fisk Street Plant, Chicago, 370.
advantages for employees, 381.
boiler room equipment, 373.
building, 371.
condenser plant, 377.
electrical equipment, 380.
oiling system, 378.
steam piping, 374.
switching room, 380.
turbo-generators, 374.
Fittings of exhaust piping, 218.
of high-pressure piping, 195.
Flanges, pipe, 195.
Floors, 48.
architectural features, 76.
Floor beams, 65.
Floor loads, structural steel, 63.
Forced draft, 127.
Forms, concrete, 47.
Foundations, 41.
location of, 47.
Foundations — *continued.*
size of, 46.
waterproofing of, 48.

G.

Gallery, switchboard, 52.
Galleries, architectural features, 78.
General layout of power plants, 12.
Generators, 274.
leads of, 278.
tests of, 333.
Twin Municipal Plant, Vienna, 393.
59th Street Plant, New York, 357.
Grate surface, 89.
Grates, 99, 104.
Grouting, 48.
Guyed chimneys, 144.

H.

Hangers, pipe, 190.
Heat value of coal, 105.
Heaters, feed-water, 154.
Heating, building, 58.
Heating surface of boilers, 88.
High-pressure piping, 181.
House pumps, 266.
Hot well piping, 220.
Hot well pumps, 266.

I.

Impulse turbines, 232.
Inclined grates, 102.
Induced draft, 128.
Inspection, structural steel, 66.
Insulation of steel frame, 68.

J.

Jet condenser, 246.

L.

Labor, local supply, 12.
Ladders, chimney, 146.
Land, cost, 11.
Layout, general, of power plants, 12.
Layout, St. Denis Plant, Paris, 336.
Leakage of smoke flues, 133.
Lighting, building, 58.

Lightning arresters, chimney, 147.
Lining of chimneys, 145.
Local labor supply, 12.
Location of foundation, 47.
  of power plants, 9.
Low-pressure piping, 217.
  covering, 221.

M.

Masonry, weight, 46.
Mat construction, concrete, 42.
Material of buildings, 48.
  of chimneys, 136.
  of exhaust piping, 218.
  of high-pressure piping, 195.
  of superheaters, 163.
Mechanical draft, 127.
Mechanical stokers, 99.
  advantages and disadvantages, 99.
  chain grates, 102.
  inclined grates, 102.
  system of, 101.
  underfeed, 102.

O.

Oil, cooling system, Chelsea, London, 368.
  filtering tanks, 269.
  piping, 272.
  pumps, 268, 271.
  required, 268.
  supply tanks, 271.
  switches, 285.
Oiling system, 268.
  Fisk Street Plant, Chicago, 378.
  59th Street Plant, New York, 361.
Open feed-water heater, 154.
Operating force, St. Denis Plant, Paris, 349.
Overhead Bunkers, 36.

P.

Painting, structural steel, 66.
Piles, concrete, 43.
  exposed coal, 28.
  test of, 44.
Piping, anchors, 189.
  boiler blow-off, 216.

Piping — *continued.*
  boiler feed, 215.
  Chelsea Plant, London, 367.
  circulating water, 220.
  covering, 213.
  drip, 210.
  expansion, 188.
  fittings, 195.
  flanges, 195.
  general consideration, 182.
  hangers, 190.
  high-pressure, 181.
  hot well, 220.
  low-pressure, 217.
  oil, 272.
  size of high-pressure, 181.
  size of exhaust piping, 217.
  supports, 190.
  system of high-pressure, 183.
  trenches for, 51, 78.
  vacuum, 220.
  valves, 206.
Piping, steam, Fisk Street, Chicago, 374.
  59th Street Plant, New York, 355.
  Twin Municipal Plant, Vienna, 392.
Plants, small, boilers, 306.
  boiler feed-water supply, 307.
  coal and ash handling systems, 305.
  condensers, 312.
  conclusion, 316.
  design of, 292.
  exciters and air compressor, 313.
  flues and smokestack, 308.
  foundation, 296.
  location, 296.
  masonry, 300.
  sanitary and architectural features, 302.
  steam piping, 309.
  superstructure, 298.
  switchboard and wiring system, 313.
  turbines and generator, 311.
  type and size, 294.
Plumbing, 56.
Potomac Plant, Washington, D.C., dimensions and data, 399.
Power plants, cost of, 4.
  efficiency of, 2.

Power plants — *continued.*
general layout of, 12.
location of, 9.
practical problems, 1.
steel of recent, 65.
testing of, 318.
Prime movers, 222.
size of, 224.
tests of, 325.
Pumping machinery, 262.
Pumps, air, 266.
boiler feed, 268.
circulating water, 264.
fire, 268.
house, 266.
hot well, 266.
oil, 268, 271.
steam or electric drive, 262.
Purifier, Dervaux-Reisert, 150.

Q.

Quadruple expansion engines, 230.

R.

Radial brick chimneys, 136.
Reciprocating engine, classification of, 225.
Reciprocating engines, 225.
Reinforced concrete chimneys, 140.
Reisert purifier, 150.
Roof construction, structural steel, 58, 59.
leaders, structural steel, 59.
Runway, crane, 61.

S.

Safety of boilers, 86.
Sarco CO_2 recorder, 116.
Saturated steam, 175.
Screens, area of, 39.
Setting of boilers, 91.
Shut-off gates, condenser water, 39.
Site, selection of, 41.
Small plants, design of, 292.
Smoke flue, 59th Street, New York, 354.
Smoke flues, 131.
character of, 131.
dampers, 133.
doors, 133.

Smoke flues — *continued.*
expansion joints, 132.
leakage of, 133.
shape of, 131.
size of, 131.
Soil, bearing power of, 44.
character of, 12, 41.
test holes, 41.
Spontaneous combustion, 29.
St. Denis Plant, Paris, 336.
auxiliary electrical equipment, 346.
boiler room, 341.
coal and ash handling systems, 340.
condenser plant, 344.
dimensions and data, 423.
feed-water plant, 342.
layout, 336.
operating force, 349.
switching room, 348.
turbo-generator, 343.
Stairways, 56.
Steam blowers, 130.
Steam, saturated, 175.
superheated, 175.
consumption of auxiliaries, 263.
or electric driven pumps, 262.
Steel chimneys, 142.
Steel, structural, 59.
Stokers, mechanical, 99.
Storage battery, 290.
Storage of boiler feed-water, 150.
of coal, 27.
Structural steel, 59.
building framing, 61.
building material, 61.
character of, 68.
crane runway, 61.
expansion joints, 64.
fiber stresses, 64.
floor loads, 63.
frame insulation, 68.
inspection, 66.
of plants, 65.
painting, 66.
roof, 58.
roof construction, 59.
roof leaders, 59.

Structural steel — *continued.*
types of columns, 62.
workmanship, 65.
Substructure, Chelsea Plant, London, 361.
Superheated steam, 175.
Superheaters, 163.
circulation of steam, 166.
classification, 163.
controlling temperature, 167.
cross-section, 164.
flow of gases, 166.
material of, 163.
size of, 172.
types of, 173.
velocity of steam in, 171.
Supports, pipe, 190.
Surface condenser, 248.
Switches, oil, 285.
Switchboards, 288.
architectural features, 80.
gallery, 52.
Twin Municipal Plant, Vienna, 394.
Switching room, 25, 278.
Chelsea Plant, London, 369.
Fisk Street Plant, Chicago, 380.
St. Denis Plant, Paris, 348.

T.

Test holes, soil, 41.
Test, Twin Municipal Plant, Vienna, 397.
Tests of boilers, 318.
of engine, 325.
of generator, 333.
of piles, 44.
of prime movers, 325.
of turbines, 327.
Testing power plants, 318.
Toilets, 56.
Trenches, pipe, 51, 78.
Trimming of boilers, 92.
Tunnels, area of condenser water, 39.
arrangement of condenser water, 39.
condenser water, 38.
Turbine tests, 327.
Turbine and engine, comparison, 222.
Turbines, 231.
classification of, 231.
Turbines — *continued.*
compound impulse, 233.
reaction, 238.
single impulse, 232.
Turbo-generators, Chelsea Plant, London, 366.
59th Street Plant, New York, 359.
Fisk Street Plant, Chicago, 374.
St. Denis Plant, Paris, 343.
Twin Municipal Plant, Vienna, 381.
boiler feed-water supply, 387.
boiler room, 387.
chimneys, 392.
coal handling system, 384.
condenser water supply, 384.
crane, 394.
engines, 392.
exciters, 394.
generators, 393.
steam piping, 392.
switchboard, 394.
tests, 397.

U.

Underfeed stoker, 102.
Unit system, complete, 17.

V.

Vacuum breaker, 252.
Vacuum piping, 220.
Valves, 206.
Ventilation, 53.
Volume of power houses per K.W. capacity, 436.

W.

Walls, 52.
architectural features of, 78.
Water circulation in boilers, 88.
Water purifier, 150.
Water required, condenser, 244.
Water supply, 11.
condenser, 38.
Waterproofing of foundations, 48.
Weight of masonry, 46.
Windows, 52.
architectural features, 76.
Wiring diagrams, 282.

LIST OF WORKS
ON
ELECTRICAL SCIENCE

PUBLISHED AND FOR SALE BY

D. VAN NOSTRAND COMPANY,

23 Murray and 27 Warren Streets, New York.

ABBOTT, A. V. The Electrical Transmission of Energy. A Manual for the Design of Electrical Circuits. Fifth Edition, revised and rewritten. With many Diagrams and Engravings and Folding Plates. 8vo, cloth. Net, $5.00.

ANDERSON, GEO. L., A.M. (Capt. U.S.A.). Handbook for the Use of Electricians in the operation and care of Electrical Machinery and Apparatus of the United States Seacoast Defenses. Prepared under the direction of Lieut.-General Commanding the Army. Illustrated. 8vo, cloth. $3.00.

ARNOLD, E. Armature Windings of Direct-Current Dynamos. Extension and Application of a general Winding Rule. Translated from the original German by Francis B. DeGress, M.E. Illustrated. 8vo, cloth. $2.00.

ASHE, S. W., and KEILEY, J. D. Electric Railways, Theoretically and Practically Treated—Rolling Stock. With Diagrams and Folding Plates. 12mo, cloth, 290 pp. Illustrated. Net, $2.50.

Vol. II. Engineering Preliminaries, Substations, and the Distributing System. 12mo, cloth. Illustrated. 282 pp. Net, $2.50.

ATKINSON, A. A., Prof. (Ohio Univ.). Electrical and Magnetic Calculations. For the use of Electrical Engineers and others interested in the Theory and Application of Electricity and Magnetism. Second Edition, revised. Illustrated. 8vo, cloth. Net, $1.50.

ATKINSON, PHILIP. The Elements of Dynamic Electricity and Magnetism. Fourth Edition. Illustrated. 8vo, cloth. $2.00.

—— **Elements of Electric Lighting,** including Electric Generation, Measurement, Storage, and Distribution. Tenth Edition, fully revised and new matter added. Illustrated. 8vo, cloth. $1.50.

—— **Power Transmitted by Electricity and Applied by the Electric Motor,** including Electric Railway Construction. Illustrated. Fourth Edition, fully revised and new matter added. 8vo, cloth. $2.00.

LIST OF WORKS ON ELECTRICAL SCIENCE.

AYRTON, HERTHA. The Electric Arc. 8vo, cloth. Illustrated. 479 pp. Net, $5.00.

BIGGS, C. H. W. First Principles of Electricity and Magnetism. Illustrated. 12mo, cloth. $2.00.

BLAKESLEY, T. H. Papers on Alternating Currents of Electricity. For the use of Students and Engineers. Third Edition, enlarged. 12mo, cloth. $1.50.

BOTTONE, S. R. Electric Bells and All about Them. 12mo, cloth. 50 cents.

—— **Electrical Instrument-Making for Amateurs.** A Practical Handbook. Enlarged by a chapter on "The Telephone." Sixth Edition. With 48 Illustrations. 12mo, cloth. 50 cents.

—— **Electric Motors, How Made and How Used.** 12mo, cloth. 75 cents.

BOWKER, WM. R. Dynamo, Motor, and Switchboard Circuits for Electrical Engineers: a practical book dealing with the subject of Direct, Alternating and Polyphase Currents. With over 100 Diagrams and Engravings. 8vo, cloth. Illustrated. Net, $2.25.

CHILD, CHAS. T. The How and Why of Electricity: a book of information for non-technical readers, treating of the properties of Electricity, and how it is generated, handled, controlled, measured, and set to work. Also explaining the operation of Electrical Apparatus. 8vo, cloth. Illustrated. $1.00.

COOPER, W. R. Primary Batteries: their Theory, Construction, and Use. 8vo, cloth, 324 pp. 131 Illustrations. Net, $4.00.

CROCKER, F. B., and WHEELER, S. S. The Management of Electrical Machinery. Being a *thoroughly revised and rewritten edition* of the authors' **"Practical Management of Dynamos and Motors."** 12mo, cloth, 223 pp. Illustrated. Net, $1.00.

CROCKER, F. B. Electric Lighting. A Practical Exposition of the Art for the use of Electricians, Students, and others interested in the Installation or Operation of Electric-Lighting Plants. Volume I.: The Generating Plant. Seventh Edition, entirely revised. 8vo, cloth. $3.00. Volume II.: Distributing System and Lamps. Sixth Edition. 8vo, cloth. Each, $3.00.

DESMOND, CHAS. Electricity for Engineers. Part I.: Constant Current. Part II.: Alternate Current. Revised Edition. Illustrated. 12mo, cloth. $2.50.

DIBDIN, W. J. Public Lighting by Gas and Electricity. With many Tables, Figures, and Diagrams. 8vo, cloth. Illustrated. 537 pp. $8.50.

DYNAMIC ELECTRICITY; Its Modern Use and Measurement, chiefly in its application to Electric Lighting and Telegraphy, including: 1. Some Points in Electric Lighting, by Dr. John Hopkinson. 2. On the Treatment of Electricity for Commercial Purposes, by J. N. Shoolbred. 3. Electric-Light Arithmetic, by R. E. Day, M.E. 18mo, boards. (No. 71 Van Nostrand's Science Series.) 50 cents.

EWING, J. A. Magnetic Induction in Iron and other Metals. Third Edition, revised. Illustrated. 8vo, cloth. $4.00.

FISHER, H. K. C., and DARBY, W. C. Students Guide to Submarine Cable Testing. Third Edition, new, enlarged. 8vo, cloth. Illustrated. Net, $3.50.

FISHER, W. C. The Potentiometer and Its Adjuncts. 8vo, cloth. Net, $2.25.

FLEMING, J. A., Prof. The Alternate-Current Transformer in Theory and Practice. Vol. I.: The Induction of Electric Currents. 500 pp. Fifth Issue. Illustrated. 8vo, cloth. $5.00. Vol. II.: The Utilization of Induced Currents. Third Issue. 594 pp. Illustrated. 8vo, cloth. $5.00.

—— **Electric Lamps and Electric Lighting.** 8vo, cloth. $2.50.

—— **A Handbook for the Electrical Laboratory and Testing-room.** 2 vols. 8vo, cloth. Each, $5.00.

FOSTER, H. A. Electrical Engineers' Pocket Book. With the Collaboration of Eminent Specialists. A handbook of useful data for Electricians and Electrical Engineers. With innumerable Tables, Diagrams, and Figures. The most complete book of its kind ever published, treating of the latest and best Practice in Electrical Engineering. Fifth Edition, revised. Pocket size, full leather, 1150 pp. Thumb index. $5.00.

GERHARDI, C. H. W. Electricity Meters. 8vo, cloth, 337 pp. 220 Illustrations. Net, $4.00.

GORE, GEORGE, Dr. The Art of Electrolytic Separation of Metals (Theoretical and Practical). Illustrated. 8vo, cloth. $3.50.

GRAY, J. Electrical Influence Machines: Their Historical Development and Modern Forms. With Instructions for making them. Second Edition, revised and enlarged. With 105 Figures and Diagrams. 12mo, cloth. Illustrated. $2.00.

HAMMER, W. J. Radium, and Other Radio-active Substances; Polonium, Actinium, and Thorium. With a consideration of Phosphorescent and Fluorescent Substances, the properties and applications of Selenium, and the treatment of disease by the Ultra-Violet Light. With Engravings and Plates. 8vo, cloth. Illustrated. $1.00.

HASKINS, C. H. The Galvanometer and its Uses. A Manual for Electricians and Students. Fourth Edition, revised. 12mo, morocco. $1.50.

—— **Transformers: Their Theory, Construction, and Application Simplified.** Illustrated. 12mo, cloth. $1.25.

HAY, A. Alternating Currents: Their Theory, Generation, and Transformation. 8vo, cloth. Illustrated. Net, $2.50.

—— **Introductory Course of Continuous-Current Engineering.** 8vo, cloth, 327 pp. 183 Illustrations. Net, $2.50.

HEAVISIDE, O. Electromagnetic Theory. 8vo, cloth. 2 vols. Each, $5.00.

HOBBS, W. R. P. The Arithmetic of Electrical Measurements. With numerous examples, fully worked. Ninth Edition. 12mo, cloth. 50 cents.

HOPKINS, N. M. Experimental Electrochemistry, Theoretically and Practically Treated. Profusely illustrated with 130 new drawings, diagrams, and photographs, accompanied by a Bibliography. 8vo, cloth. Illustrated. 284 pages. Net, $3.00.

HUTCHINSON, R. W., Jr. Long-Distance Electric Power Transmission: Being a Treatise on the Hydro-Electric Generation of Energy; Its Transformation, Transmission, and Distribution. 12mo, cloth, 344 pp. Illus. Net, $3.00.

INCANDESCENT ELECTRIC LIGHTING. A Practical Description of the Edison System, by H. Latimer. To which is added: The Design and Operation of Incandescent Stations, by C. J. Field; A Description of the Edison Electrolyte Meter, by A. E. Kennelly; and a Paper on the Maximum Efficiency of Incandescent Lamps, by T. W. Howell. Illustrated. 16mo, cloth. (No. 57 Van Nostrand's Science Series.) 50 cents.

INDUCTION COILS: How Made and How Used. Third Edition. 16mo, cloth. (No. 53 Van Nostrand's Science Series.) 50 cents.

JEHL, FRANCIS, Member A.I.E.E. The Manufacture of Carbons for Electric Lighting and other purposes. Illustrated with numerous Diagrams, Tables, and Folding Plates. Illustrated. 8vo, cloth. $4.00.

JONES, HARRY C. Electrical Nature of Matter and Radioactivity. 12mo, cloth. $2.00.

KAPP, GISBERT, C. E. Electric Transmission of Energy and its Transformation, Subdivision, and Distribution. A Practical Handbook. Fourth Edition, thoroughly revised. 12mo, cloth. $3.50.

—— **Alternate-Current Machinery.** 190 pp. Illustrated. (No. 96 Van Nostrand's Science Series.) 50 cents.

KELSEY, W. R. Continuous-Current Dynamos and Motors, and their Control; being a series of articles reprinted from the "Practical Engineer," and completed by W. R. Kelsey, B.Sc. With Tables, Figures, and Diagrams. 8vo, cloth. Illustrated. $2.50.

KEMPE, H. R. A Handbook of Electrical Testing. Fifth Edition. 200 Illustrations. 8vo, cloth. $6.00.

KENNEDY, R. Modern Engines and Power Generators. 4to, cloth. Illustrated. 6 vols. Each, $3.50. Complete set, $15.00.

—— **Electrical Installations of Electric Light, Power, and Traction Machinery.** 5 vols. 8vo, cloth. Illustrated. Each, $3.50. Complete set, $15.00.

KENNELLY, A. E. Theoretical Elements of Electro-Dynamic Machinery. Vol. I. Illustrated. 8vo, cloth. $1.50.

KINZBRUNNER, C. Continuous-Current Armatures: Their Winding and Construction. 8vo, cloth, 80 pp. 79 Illustrations. Net, $1.50.

—— **Alternate-Current Windings: Their Theory and Construction.** 8vo, cloth, 80 pp. 89 Illustrations. Net, $1.50.

LIVERMORE, V. P., and WILLIAMS, J. How to Become a Competent Motorman: being a practical treatise on the proper method of operating a street-railway motor-car; also giving details how to overcome certain defects. 16mo, cloth. Illustrated. Revised Edition. In Press.

LOCKWOOD, T. D. Electricity, Magnetism, and Electro-Telegraphy. A Practical Guide and Handbook of General Information for Electrical Students, Operators, and Inspectors. Fourth Edition. Illustrated. 8vo, cloth. $2.50

LORING, A. E. A Handbook of the Electro-Magnetic Telegraph. Fourth Edition, revised. 16mo, cloth. (No. 39 Van Nostrand's Science Series.) 50 cents.

LUPTON, A. PARR, G. D. A., and PERKIN, H. Electricity Applied to Mining. With Tables, Diagrams, and Folding Plates. Second Edition, revised and enlarged. 8vo, cloth, 280 pp. Illustrated. Net, $4.50.

MANSFIELD, A. N. Electromagnets: Their Design and Construction. (No. 64 Van Nostrand's Science Series.) 50 cents.

MURRAY, JAS. ERSKINE. A Handbo·k of Wireless Telegraphy: Its Theory and Practice. 8vo, cloth, 320 pp. Illustrated. Net, $3.50.

NIPHER, FRANCIS E., A.M. Theory of Magnetic Measurements. With an Appendix on the Method of Least Squares. 12mo, cloth. $1.00.

OHM, G. S., Dr. The Galvanic Circuit Investigated Mathematically. Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thos. D. Lockwood. 12mo, cloth. (No. 102 Van Nostrand's Science Series.) 50 cents.

OUDIN, MAURICE, A. M. S. Standard Polyphase Apparatus and Systems. Illustrated, with many Photo-reproductions, Diagrams, and Tables. Fifth Edition, revised. 8vo, cloth. $3.00.

PALAZ, A. Treatise on Industrial Photometry. Specially applied to Electric Lighting. Translated from the French by G. W. Patterson, Jr., Assistant Professor of Physics in the University of Michigan, and M. R. Patterson, B.A. Second Edition. Fully Illustrated. 8vo, cloth. $4.00.

PARSHALL, H. F., and **HOBART, H. M. Armature Windings of Electric Machines.** Third Edition. With 140 full-page Plates, 65 Tables, and descriptive letter-press. 4to, cloth. $7.50.

—— **Electric Railway Engineering.** 4to, cloth. Illustrated with many Diagrams and Plates. Net, $10.00.

PERRINE, F. A. C., A.M., D.Sc. Conductors for Electrical Distribution: Their Manufacture and Materials, the Calculation of Circuits, Pole-Line Construction, Underground Working, and other Uses. Second Edition, revised. 8vo, cloth. Illustrated. Net, $3.50.

PLANTE, GASTON. The Storage of Electrical Energy, and Researches in the Effects created by Currents combining Quantity with High Tension. Translated from the French by Paul B. Elwell. 89 Illustrations. 8vo. $4.00.

POPE, F. L. Modern Practice of the Electric Telegraph. A Handbook for Electricians and Operators. An entirely new work, revised and enlarged, and brought up to date throughout. Illustrations. 8vo, cloth. $1.50.

RAPHAEL, F. C. Localization of Faults in Electric-Light Mains. Second Edition, revised. 8vo, cloth. Illustrated. Net, $3.00.

RAYMOND, E. B. Alternating-Current Engineering, Practically Treated. With many Figures and Diagrams. Third Edition, revised. 8vo, cloth. Illustrated. Net, $2.50.

RUHMER, E. Wireless Telephony: Its Theory and Practice. Translated from the German by Jas. Erskine Murray. 8vo, cloth, 224 pp. 143 Illustrations. Net, $3.50.

SALOMONS, Sir DAVID, M.A. Electric-Light Installations. A Practical Handbook. Seventh Edition, revised and enlarged. Vol. I.: Management of Accumulators. Illustrated. 12mo, cloth, 178 pp. Ninth Edition, revised. Net, $2.50. Vol. II.: Apparatus. Illustrated. 12mo, cloth. $2.25. Vol. III.: Application. Illustrated. 12mo, cloth. $1.50.

SEVER, G. F. Electrical Engineering Experiments and Tests on Direct-Current Machinery. With Diagrams and Figures. Second Edition. 8vo, pamphlet. Illustrated. Net, $1.00.

SEVER, G. F., and TOWNSEND, F. Laboratory and Factory Tests in Electrical Engineering. Second Edition, thoroughly revised and enlarged. 8vo, cloth. Illustrated. 225 pp. Net, $2.50.

SEWALL, C. H. Wireless Telegraphy. With Diagrams and Figures. Second Edition, corrected. 8vo, cloth. Illustrated. Net, $2.00.

—— **Lessons in Telegraphy.** 12mo, cloth. Illustrated. In Press.

SEWELL, T. Elements of Electrical Engineering. Second Edition, revised. 8vo, cloth. Illustrated. 432 pp. Net, $3.00.

—— **The Construction of Dynamos.** 8vo, cloth, 316 pp. With 250 Special Engravings and Diagrams. Net, $3.00.

SHELDON, S., Ph.D., and MASON, H., B.S. Dynamo-Electric Machinery: Its Construction, Design, and Operation. Direct-Current Machines. Sixth Edition, revised. Illustrated. 8vo, cloth. Net, $2.50.

—— **Alternating-Current Machines:** being the second volume of the authors' "Dynamo-Electric Machinery: its Construction, Design, and Operation." With many Diagrams and Figures. (Binding uniform with Volume I.) Fifth Edition. Illustrated. 8vo, cloth. Net, $2.50.

SNELL, ALBION T. Electric Motive Power. The Transmission and Distribution of Electric Power by Continuous and Alternating Currents. With a Section on the Applications of Electricity to Mining Work. Second Edition, revised. Illustrated. 8vo, cloth. $4.00.

SODDY, F. Radio-activity: an Elementary Treatise from the Standpoint of the Disintegration Theory. Fully Illustrated, and with a complete table of Contents and Extended Index. 8vo, cloth. Illustrated. Net, $3.00.

SWINBURNE, JAS., and WORDINGHAM, C. H. The Measurement of Electric Currents. Electrical Measuring Instruments. Meters for Electrical Energy. Edited, with Preface, by T. Commerford Martin. Folding Plate and numerous Illustrations. 16mo, cloth. 50 cents.

SWOOPE, C. WALTON. Practical Lessons in Electricity: Principles, Experiments, and Arithmetical Problems. An Elementary Text-book. With numerous Tables, Formulæ, and two large Instruction Plates. Ninth Edition, Twelfth Thousand. Illustrated. 8vo, cloth. Net, $2.00.

THOM, C., and JONES, W. H. Telegraphic Connections, embracing recent methods in Quadruplex Telegraphy. 20 Colored Plates. 8vo, cloth. $1.50.

THOMPSON, S. P., Prof. Dynamo-Electric Machinery. With an Introduction and Notes by Frank L. Pope and H. R. Butler. Fully Illustrated. (No. 66 Van Nostrand's Science Series.) 50 cents.

—— **Recent Progress in Dynamo-Electric Machines.** Being a Supplement to "Dynamo-Electric Machinery." Illustrated. 12mo, cloth. (No. 75 Van Nostrand's Science Series.) 50 cents.

—— **Dynamo-Electric Machinery.** Vol. I. 8vo, cloth, 996 pp. 573 Illustrations. 4 Colored and 32 Folding Plates. $7.50.

—— Vol. II. **Alternating-Current Machines.** 848 pp. 546 Illustrations. 15 Colored Plates, 24 Folding Plates. 8vo, cloth. $7.50.

TUNZELMANN, G. W. de. Electricity in Modern Life. Illustrated. 12mo, cloth. $1.25.

UNDERHILL, C. R. The Electromagnet: Being a new and revised edition of "The Electromagnet," by Townsend Walcott, A. E. Kennelly, and Richard Varley. With Tables and Numerous Figures and Diagrams. 12mo, cloth. Illustrated. $1.50.

URQUHART, J. W. Dynamo Construction. A Practical Handbook for the use of Engineer Constructors and Electricians in Charge. Illustrated. 12mo, cloth $3.00.

URQUHART, J. W. Electric Ship-Lighting. A Handbook on the Practical Fitting and Running of Ship's Electrical Plant, for the use of Ship Owners and Builders, Marine Electricians, and Sea-going Engineers in Charge. 88 Illustrations. 12mo, cloth. $3.00.

—— **Electric-Light Fitting.** A Handbook for Working Electrical Engineers, embodying Practical Notes on Installation Management. Second Edition, with additional chapters. With numerous Illustrations. 12mo, cloth. $2.00.

—— **Electroplating.** Fourth Edition. 12mo, cloth. $2.00.

—— **Electrotyping.** 12mo, cloth. $2.00.

WADE, E. J. Secondary Batteries: Their Theory, Construction, and Use. With innumerable Diagrams and Figures. 8vo, cloth. Illustrated. Net, $4.00.

WALKER, FREDERICK. Practical Dynamo-Building for Amateurs. How to Wind for any Output. Illustrated. 16mo, cloth. (No. 98 Van Nostrand's Science Series.) 50 cents.

WALKER, S. F. Electricity in Our Homes and Workshops. Fourth Edition, revised and enlarged. 12mo, cloth, 359 pp. 205 Illustrations. Net, $2.00.

—— **Electricity in Mining.** With Figures, Diagrams, and Plates. 8vo, cloth. Illustrated. 385 pp. Net, $3.50.

WALLING, B. T., Lieut.-Com. U.S.N., and MARTIN, JULIUS. Electrical Installations of the United States Navy. With many Diagrams and Engravings. 8vo. 648 pp. 300 Illustrations. Net, $6.00.

WATT. Electroplating and Refining of Metals. 8vo, cloth. Illustrated. Net $4.50.

—— **Electro-Metallurgy.** Eleventh Edition. 12mo, cloth. $1.00.

WEBB, H. L. A Practical Guide to the Testing of Insulated Wires and Cables. Illustrated. 12mo, cloth. $1.00.

WEEKS, R. W. The Design of Alternate-Current Transformer. New Edition. In press.

WEYMOUTH, F. MARTEN. Drum Armatures and Commutators. (Theory and Practice.) A complete treatise on the theory and construction of drum-winding, and of commutators for closed-coil armatures, together with a full résumé of some of the principal points involved in their design; and an exposition of armature reactions and sparking. Illustrated. 8vo, cloth. $3.00.

WILKINSON, H. D. Submarine Cable-Laying, Repairing, and Testing. 8vo, cloth. Reprinting.

This book may be kept
FOURTEEN DAYS
A fine of TWO CENTS will be charged for each day the book is kept overtime.

5 MY'32			
14 JL'32			
[illegible]			
[illegible]			
[illegible]			
Nov 9 43			
[illegible]			
29 JL'52			
[illegible]			

No. 291-B DEMCO-MADISON-WIS